Naval Surface Warfare Center
Carderock Division

West Bethesda, MD 20817-5700

NSWCCD-TR-65–97/18 April 1997

Survivability, Structures, and Materials Directorate

Technical Report

An Experimental Investigation of the Ultimate Strength of Stiffened Panels

- Volume 2, Test Data

by

Gregory J. White (USNA),

ENS Robert H. Vroman (USNR),

David P. Kihl (NSWCCD), and

Sara E. Mourning (USNA)

NSWCCD-TR-65-97/18 An Experimental Investigation of the Ultimate Strength of Stiffened Panels

DEPARTMENT OF THE NAVY

NAVAL SURFACE WARFARE CENTER, CARDEROCK DIVISION
9500 MACARTHUR BOULEVARD
WEST BETHESDA MD 20817-5700

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To: Commander, Naval Sea Systems Command (SEA 03R)

Subj: RELIABILITY BASED STRUCTURAL DESIGN PROGRAM

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Encl: (1) NSWCCD-TR-65–97/18, *An Experimental Investigation of the Ultimate Strength of Stiffened Panels - Volume 1, Results and Analyses*

(2) NSWCCD-TR-65–97/18, *An Experimental Investigation of the Ultimate Strength of Stiffened Panels - Volume 2, Test Data*

1. Reference (a) directed the Naval Surface Warfare Center, Carderock Division (NSWCCD) and the U.S. Naval Academy to investigate the failure mode and ultimate strength of longitudinally-stiffened plate commonly used in ship structures such as decks, bottoms, bulkheads and side shells. Enclosure (1) presents results for six grillages which were tested to collapse in the Grillage Test Fixture at the U.S. Naval Academy. Each grillage consisted of three stiffened panels (bays). They were nominally identical and represented approximately a 1/3rd scale model of typical warship deck structure. The grillages were made of longitudinal and transverse T-shaped stiffeners welded to flat plate; all pieces were made of mild steel. Three of the six specimens were tested under in-plane axial load only; the remaining three were tested under a combination of axial in-plane load and initial lateral pressure. The test specimens were fully instrumented with strain gages and displacement transducers to quantify the structural behavior up to and beyond ultimate collapse. Although representative plots of structural behavior are illustrated in Enclosure (1), a much more comprehensive series of test results is provided, for each test, in Enclosure (2).

2. The report compares test results from these panels with theoretical predictions of failure mode and stress. Data obtained from a literature search of similar tests performed at other facilities were also used for comparison. In so doing, we have evaluated the accuracy of theoretical predictions over a wide range of test conditions. A finite element model of the grillage specimen subjected to compressive axial was also constructed and compared to the test results.

3. The in-plane axial load test results were found to be between 4% and 8% higher than the theoretical prediction. The predictions are considered to be quite good and slightly conservative. The test results with lateral load were found to be 4% higher for the 5 psi case and about 20%

higher for the 10 psi and 20 psi loadings. The poorer agreement at higher pressures, although conservative, is attributed to a shortcoming in the way lateral deformations are assumed to magnify the axial in-plane stresses. The finite element results were found to accurately predict the ultimate strength of the grillage specimen, but did not produce good estimates of the overall deformations. Better agreement may be possible by modeling the stiffener attachments to the plating and including initial geometric imperfections. Results of the literature search revealed very few tests have been conducted on multi-bay specimens, and even fewer with combine in-plane and axial loads.

4. Comments or questions may be referred to the principal investigator, Dr. David P. Kihl, Code 653; telephone (301) 227-1956; e-mail, kihl@oasys.dt.navy.mil.

J. E. BEACH
By direction

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Enclosure (2)

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13. ABSTRACT *(Maximum 200 words)*

A series of multi-bay steel grillages were tested to collapse in the Grillage Test Fixture at the U.S. Naval Academy. The grillages were nominally 1/3-scale models of typical warship deck structures. The tests were part of a student research project investigating reliability-based design methods for stiffened panels. The six nominally identical grillage specimens were made from ordinary steel and consisted of three panels (bays) stiffened longitudinally and transversely with T-shaped stiffeners. Three specimens were tested under in-plane loads only, and three were tested with a combination of in-plane loads and initial lateral pressure. During testing, data were collected from strain gages and displacement transducers to quantify the structural behavior of the specimens under load. Theoretical predictions of failure mode and stress level are compared to observed values. The test results are also compared to results from similar tests conducted at other facilities. A finite element method analysis of the grillages subjected to compressive axial load was conducted using ABAQUS and the results compared to the test results. The data from past tests and these tests are used to evaluate the accuracy of theoretical predictions over a wide range of test conditions.

14. SUBJECT TERMS
steel grillage, in-plane loads, T-shaped stiffeners, ABAQUS, stiffened panels, reliability-based design methods

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Administrative Information

The work described herein was performed by the Department of Naval Architecture, Ocean, and Marine Engineering at the U.S. Naval Academy and the Structures and Composite Department, Code 65, of the Survivability, Structures, and Materials Directorate at the Naval Surface Warfare Center, Carderock Division under the sponsorship of the Naval Sea Systems Command (SEA 03R3). This report is submitted in partial fulfillment of Milestone H5, Sub task IIC of the Reliability Based Structural Design Program PE063564N, Project S2036-01.

Background

A series of six scaled grillage tests were conducted at the United States Naval Academy (USNA), Annapolis, Maryland during calendar years 1994 and 1995. Results of these efforts are documented in two other reports.[1,2] These reports contained only enough pertinent data to show representative behavior and support conclusions. Since other data had been collected during these tests, but not specifically included in the preceding report, it was decided that a basic data archival report would be of value as the experimental study of grillage behavior progressed.

This report therefore contains a brief introductory section which defines the overall series of tests and measurements. The data collected during each test are provided in the appendices. Most of the data are presented in graphical form and grouped by test. To facilitate comparison of data between one test and another, each section of data is organized in the same format with similar data plots presented in the same order.

Introduction

The test specimens consisted of orthogonally stiffened plate representative of ship hull girder structure. Each test specimen contained four longitudinal tee stiffeners which ran the full length of the test specimens. At the third points, the longitudinal stiffeners passed through deeper transverse stiffeners, forming a three bay test specimen. Plating in the outer two bays was slightly thicker to reduce the applied stress in the outer bays and allow a uniform load transition into the center test section. Figure 1 shows the basic test specimen which was used in each of the six tests.

The test specimens were mounted in a testing fixture capable of applying in-plane axial

compressive load, up to 360,000 pounds, into the end of the test specimen and lateral pressure load, up to 40 psi, over the plate (as opposed to stiffener) side of the test specimen. The test fixture is shown in Figure 2.

The test specimens were instrumented with sensors to monitor the structural behavior during the initial loading and ultimate collapse of the specimen. Sixty strain gages were placed on each test specimen at points of interest to measure induced strain. The strain gages were typically laid out in pairs to sense local and/or overall modes of structural instability. Strain gage locations are shown in Figure 3. Dial gages and potentiometers were also placed at various locations over each test specimen to measure deformation of the specimen as it collapsed. The axial deformation measurements were initially made using string potentiometers positioned along either longitudinal side of test specimen. Later, these axial deformation measurements were supplemented with other types of displacement transducers (dial gages and linearly variable displacement transducers (LVDTs)) when it was discovered the that the string potentiometers exhibited hysteresis as the specimen was unloaded. In some cases, longitudinal displacement was also measured by the actuator positioning LVDT. The actuator LVDT measurement, however, would also contain the elongation of the fixture itself, in addition to the compression of the test specimen. Applied load and axial deformation measurements were considered most important, since they would eventually be used to generate load shortening curves. Load shortening curves serve as the basic input for some ultimate strength prediction computer programs. Data from the dial gages, which were positioned above the center bay of the grillage, were visually monitored during the first few tests. However, the limitations of visually recording measurements, especially during a destructive test, rendered much of this data suspect. These data were therefore not included in this document.

The test specimens were positioned in the fixture such that the center of the load head

coincided with the average distance between the calculated elastic and plastic neutral axis locations shown in Figures 4 and 5. Figure 6 shows a typical test specimen mounted in the test fixture.

The series of six tests were all conducted in the same fixture on nominally identical specimens. The first three specimens, #0494, #0894 and #1094, were all tested under in-plane axial compressive load to estimate the scatter in the ultimate collapse load and overall response. The next three specimens, #0595, #0695 and #0995, were subjected to various amounts of lateral pressure before the axial in-plane compressive load was applied. Table 1 is provided to show the different load conditions considered and the ultimate load carried by each of the six test specimens.

Data Presentation Format

Test data are provided in the appendix of this report. The appendix contains data from the specimens subjected to in-plane axial load only, i.e. tests #0494, 0894 and 1094, and data from specimens subjected to a combination of in-plane axial load and initial lateral pressure, i.e. #0595, 0695 and 0995.

The data obtained from each test were similar and are therefore arranged in the same order and in the same format for each test specimen. At the beginning of each section, the first plot shows a time history of the compressive load applied to the test specimen, where "time" is measured as data records acquired. This plot shows how the specimen was loaded in increments, periodically unloaded and reloaded up to and beyond failure.

The next plot is one of end shortening versus compressive load applied. As discussed earlier, the plots may vary somewhat from specimen to specimen, depending on how the end

shortening measurement was made (string pots, actuator LVDT, or dial gages).

The next four pages illustrate the condition of the specimen before and after the test. Before load was applied, measurements were made on each test specimen to quantify the out-of-plane imperfections in the flat plate. Results are shown in both a contour plot and a topographical "relief" type plot. The same types of measurements were made again after the test was completed and are provided in the same forms for comparison.

The remainder of the figures in each group of data show plots of measured strain versus applied compressive load. The gages shown on each plot are grouped conveniently to show strain profiles across a section of the grillage, across the flange of a stiffener, or on sections of plating between stiffeners.

Test Results

All of the grillages were tested to collapse and well into the post buckling range. As shown in the time history plots of the loading sequence, several loading and unloadings of the grillage were performed. It is apparent from the time histories that each of the grillages continued to carry a significant portion of the ultimate load (on the order of 60%) after surpassing the ultimate load.

By periodically unloading the grillage and reapplying the load, the linearity of the grillage response and the magnitude of permanent deformations can be determined. After the first loading, all subsequent unloadings show an offset loading line with nominally the same slope.

The grillages collapsed in a mode triggered by a compression failure of the plating. This determination was made by an evaluation of the stress/strain relationships in the center bay of each grillage specimen. By examining the strain gage readings at each load increment, it was

determined that the plating was the first element to reach the yield stress of the material. A characteristic out-of-plane bending of the grillage was typically observed. Also apparent was the rotation of the stiffeners into an "S" shaped pattern. This observation indicates stiffener instability was ultimately the cause of the panel collapse. The ultimate collapse occurred between the transverse frames in the center bay.

When lateral pressure was present, the ultimate strength in-plane load carrying capacity of the grillages was reduced. In all cases, the lateral pressure was applied first while the ends of the grillage were held in a constant position. As the in-plane load was applied, the lateral pressure was monitored and manually adjusted to try and maintain a constant pressure on the test specimen. The lateral pressure was applied to the plate side of the grillage, forcing the grillage to bend and deflect upwards. The lateral pressure applied to the second series of grillage tests was varied from 5 psi for the first grillage, to 10 psi for the second grillage, and finally to 20 psi for the last specimen.

The failure mechanism observed in each case when lateral pressure was applied, was the same as that observed under axial load only. The uniform lateral pressure caused an initial deflection at the midspan of the stiffeners and an initial deflection of the midspan of the center plate. The collapse started in the center panel of the center bay and proceeded outward to the stiffeners. The local buckling of the plate between the stiffeners appeared to initiate bending of the stiffener web, causing it to bulge away from the upward deflection of the plate. This, in turn, causes the stiffener flange to rotate towards the center of the panel.

The three tests conducted with only in-plane loads show some scatter in ultimate load carrying capacity. Though nominally the same grillage, there were some differences in the "as tested" dimensions as well as differences in the initial deformations of the stiffeners.

When lateral pressure is present, there is a decrease in the experimental collapse stress.

A greater decrease in collapse strength is observed as the lateral pressure is increased. The plate bending caused by the lateral load usually induces a simple half-wave pattern as one would expect. Depending on the aspect ratio of the plate, this pattern will not likely match the critical buckling mode shape for the plate and therefore may actually increase the plate critical buckling stress. The lateral pressure does, however, cause the stiffeners to deflect in a sinusoidal half wave, which induces another component of stress in the panel; one which magnifies the effect of the axial stress. If the failure mode for the panel is plate-induced, moderate levels of lateral pressure may have almost no overall effect on strength, since the increase in the plate critical buckling stress may more than offset the magnified axial stress due to the deformation.

Surprisingly, the initial deflection of the plating has little to do with the ultimate strength of the panel. This is due to the fact that the usual form of initial deflection of plating is a single longitudinal and transverse wave. This mode shape is actually much stronger in axial compression than the preferred mode shape. The net result is that there can be an increase in axial strength of the plating with initial deflection. This idea ties in with the effect of lateral pressure, which also tends to induce an initial deflection of the plate in a one half-wave pattern. However, initial deflections of the stiffener appear to be more important than plating deformations in determining both the failure mode as well as the failure load. Typically, any initial deflection tends to push the stiffener in a direction which corresponds to a primary failure mode shape. The relationship between stiffener geometry and the tolerance allowed on initial deflections is an area which needs further investigation.

Table 1 - Loads applied to Test Specimens

Test	Ultimate Load (kips)	Ultimate Stress (ksi)	Lateral Pressure (psi)
0494	325.857	37.225	0
0894	300.812	34.781	0
1094	312.914	35.772	0
0595	315.663	36.104	5
0695	305.994	34.835	10
0995	296.356	34.020	20

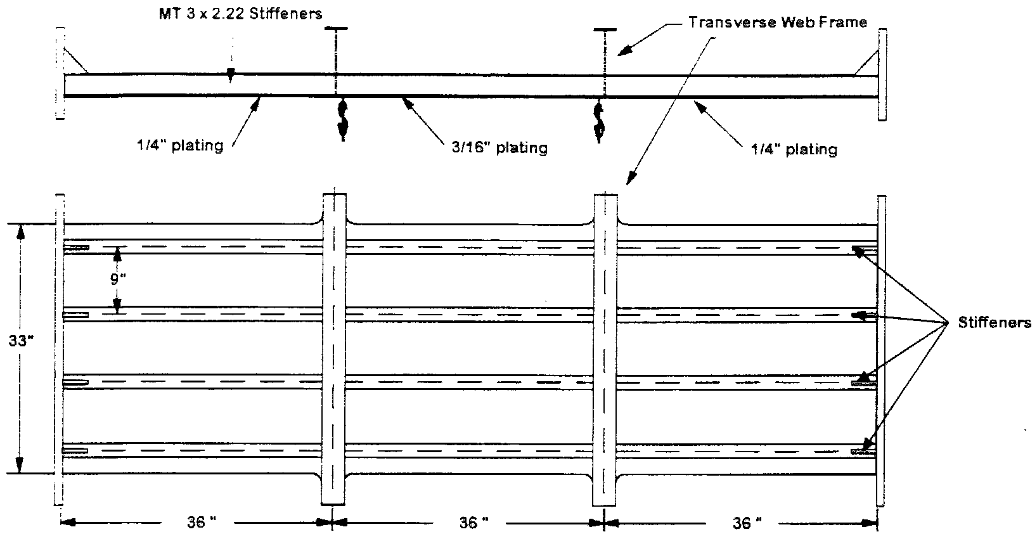


Figure 1a - Dimensions of the Grillage Specimens

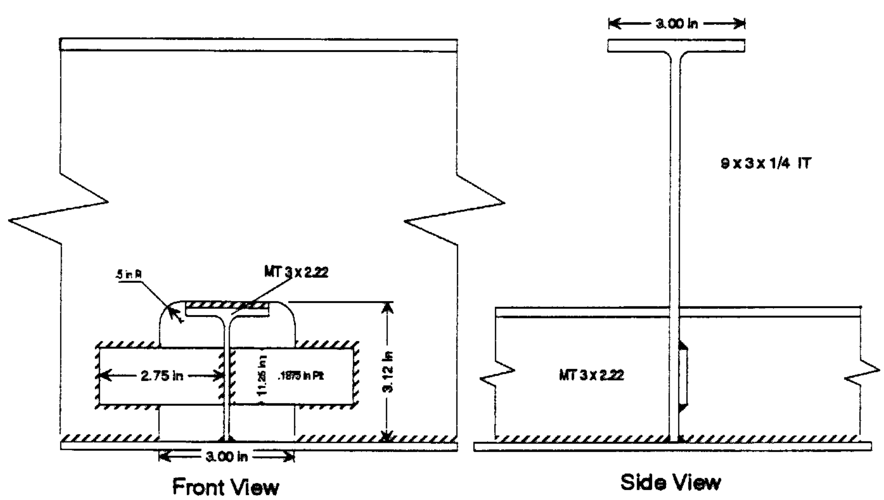


Figure 1b - Web-Stiffener Connection Details

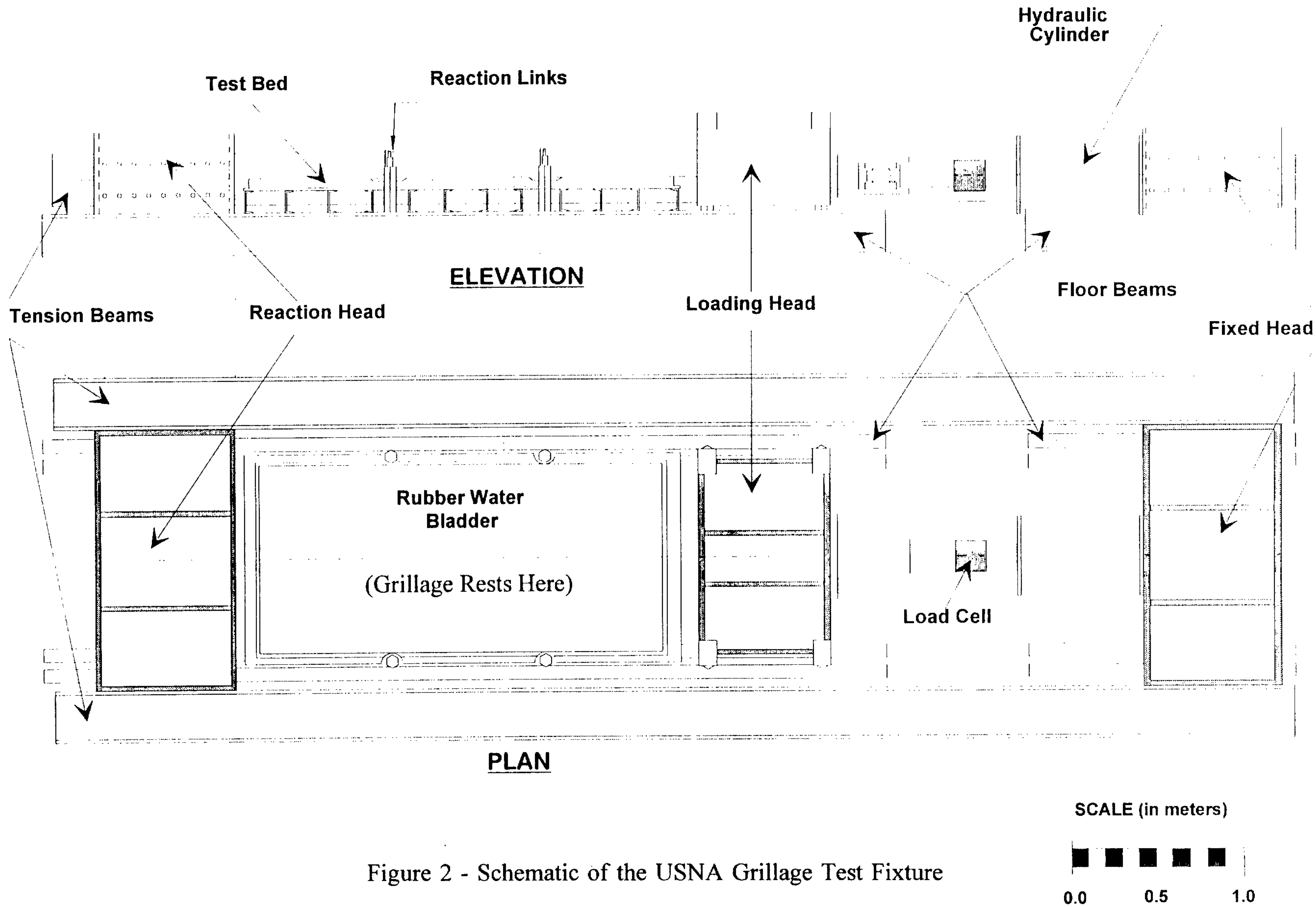


Figure 2 - Schematic of the USNA Grillage Test Fixture

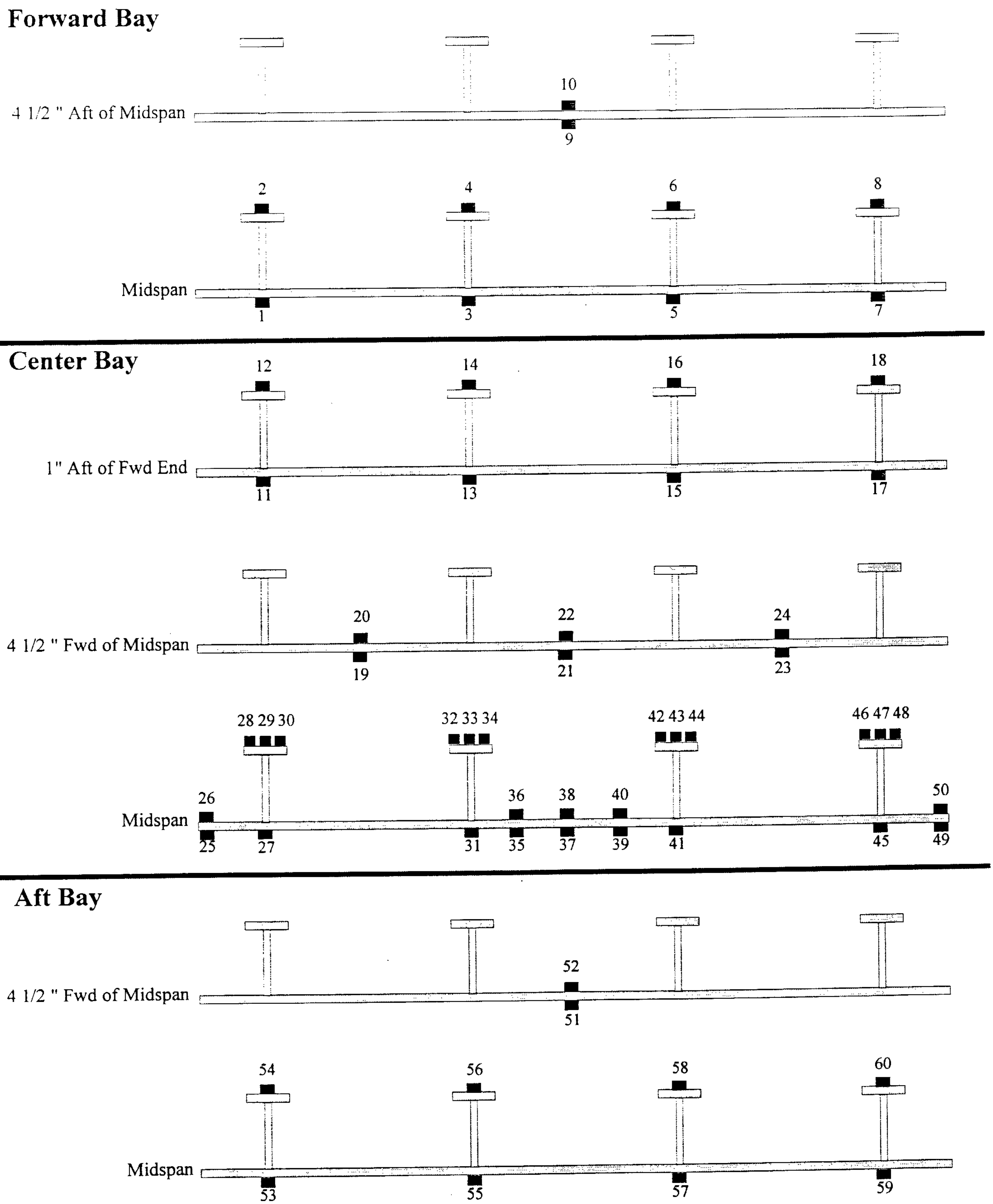
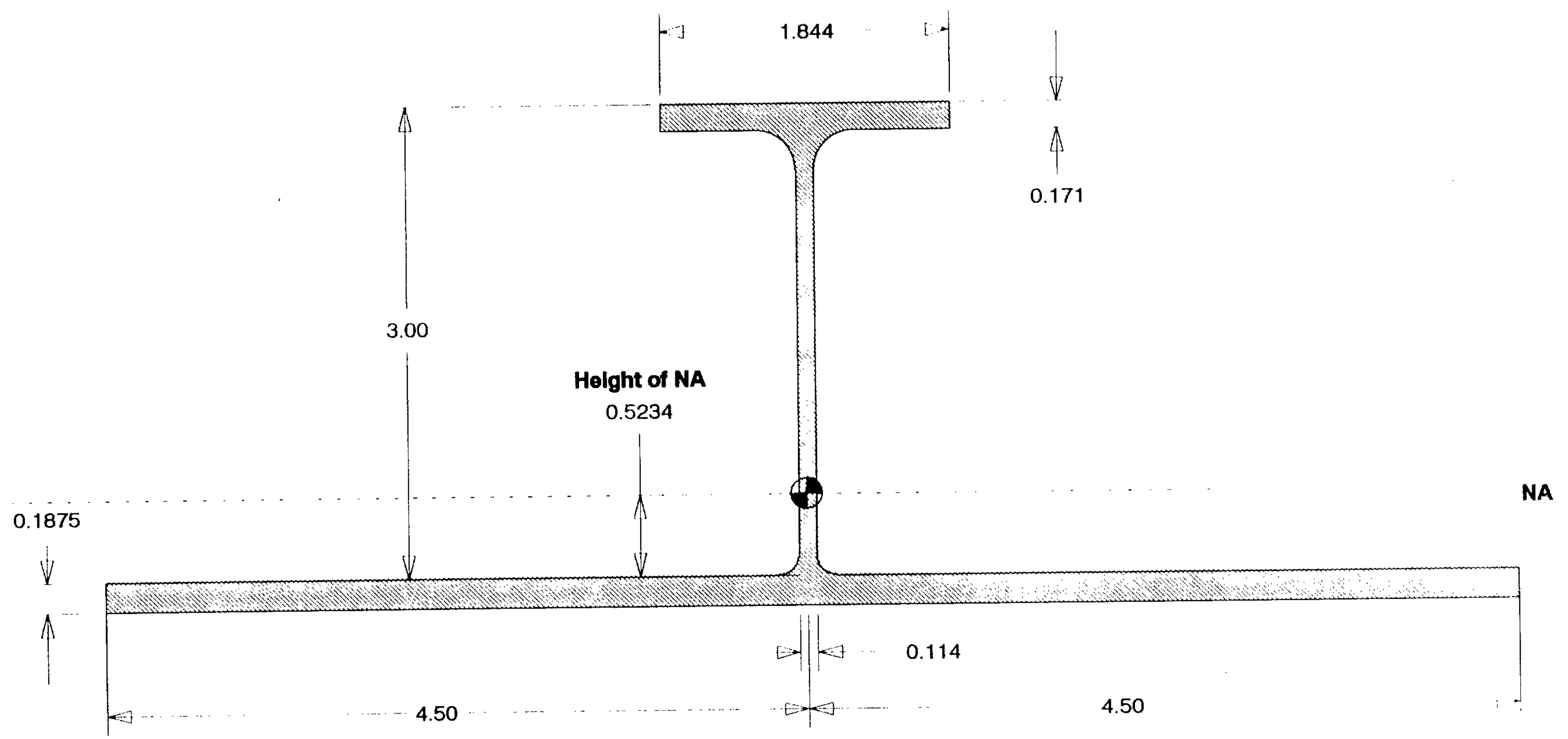


Figure 3 - Strain Gage Locations for Test Series

Calculation of the Height of the Elastic Neutral Axis



All dimensions in inches

Figure 4 - Geometry of the Stiffener-Plate Cross-Section Showing Elastic Neutral Axis

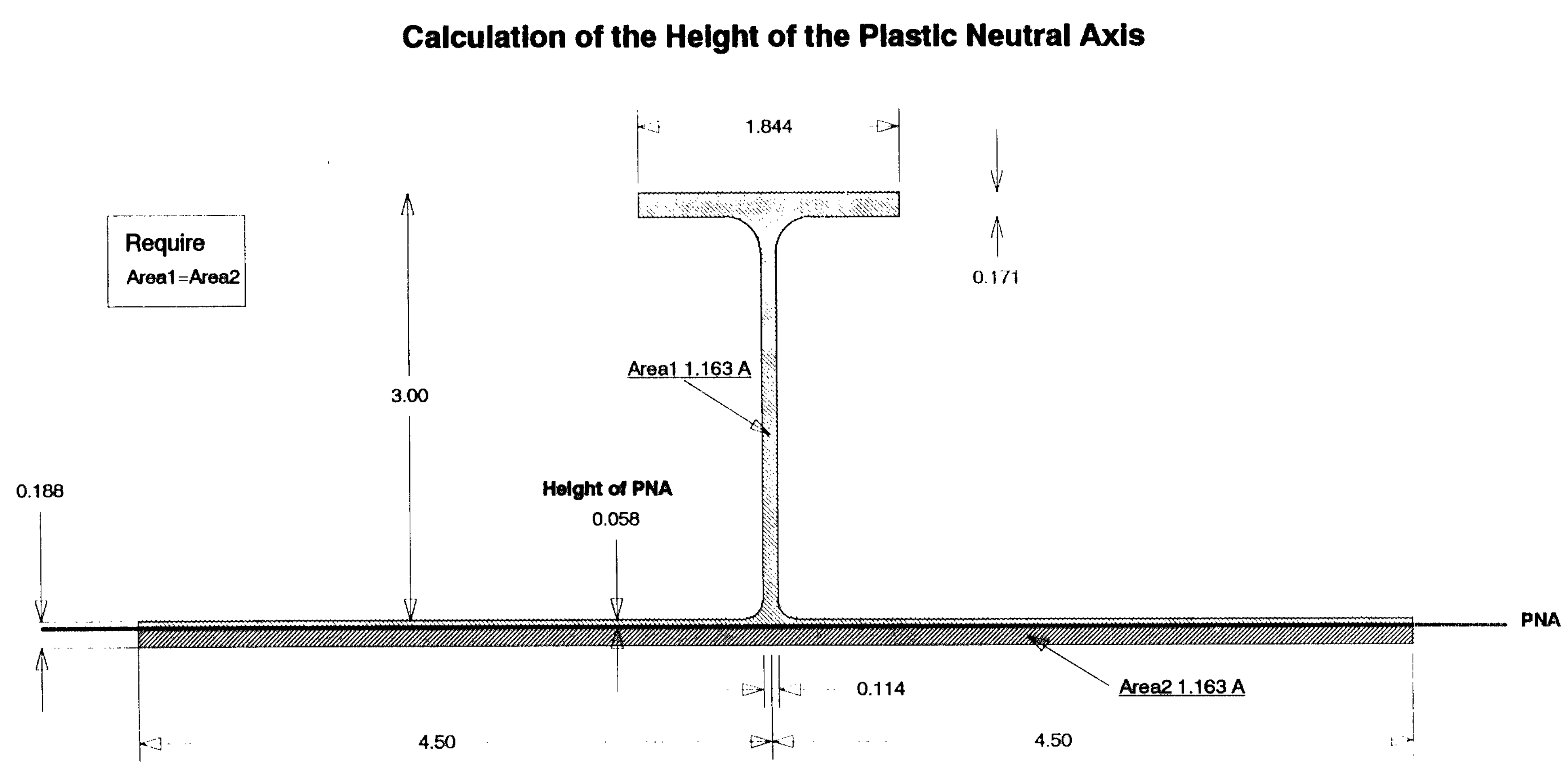


Figure 5 - Geometry of the Stiffener-Plate Cross-Section Showing Plastic Neutral Axis

All dimensions in inches

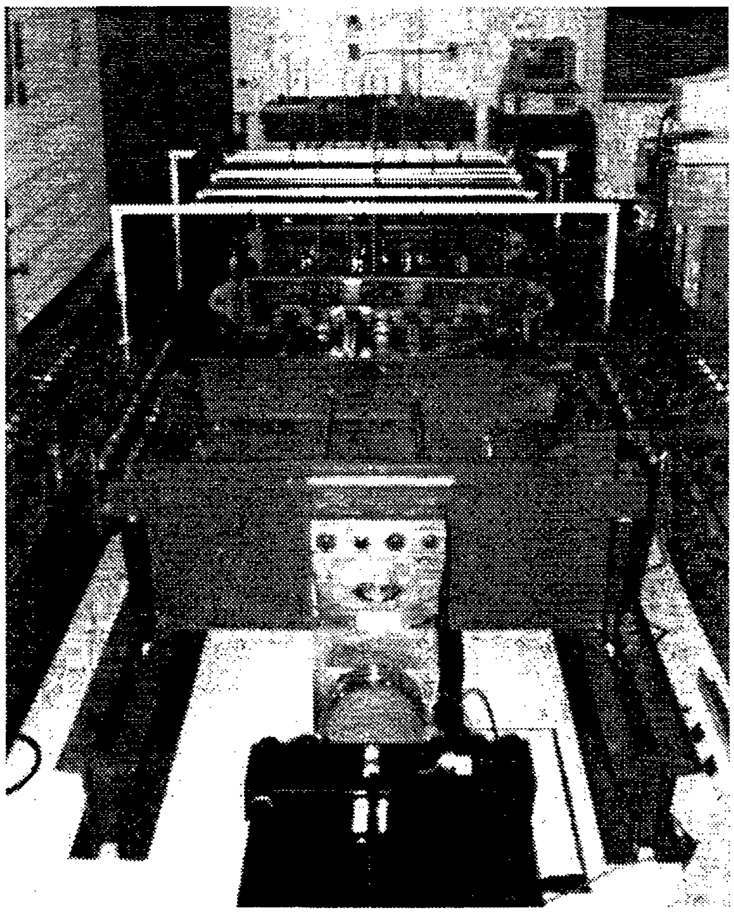


Figure 6 - Typical Grillage Specimen Before Testing

References

1. White, G.J., R.H. Vroman, D.P. Kihl, and S.E. Mouring, An Experimental Investigation of the Ultimate Strength of Stiffened Panels - Volume 1, Results and Analysis, NSWCCD-TR-65-97/18, April 1997.

2. Vroman, Robert H., An Analysis into the Uncertainty of Stiffened Panel Ultimate Strength, Trident Scholar Research Report No. 234, U.S. Naval Academy, Annapolis, MD., May, 1995.

Appendix

Grillage Data

The following table provides an index to the grillage data.

Load	Specimen	Data	Pages
Axial	0494	Load History	A-2
		Load vs. End Shortening	A-3
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		Post-Test Survey	A-6 thru A-7
		Strain vs. Applied Load	A-8 thru A-23
Axial	0894	Load History	A-24
		Load vs. End Shortening	A-25
		Pre-Test Survey	A-26 thru A-27
		Post-Test Survey	A-28 thru A-29
		Strain vs. Applied Load	A-30 thru A-48
Axial	1094	Load History	A-49
		Load vs. End Shortening	A-50
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		Strain vs. Applied Load	A-55 thru A-73
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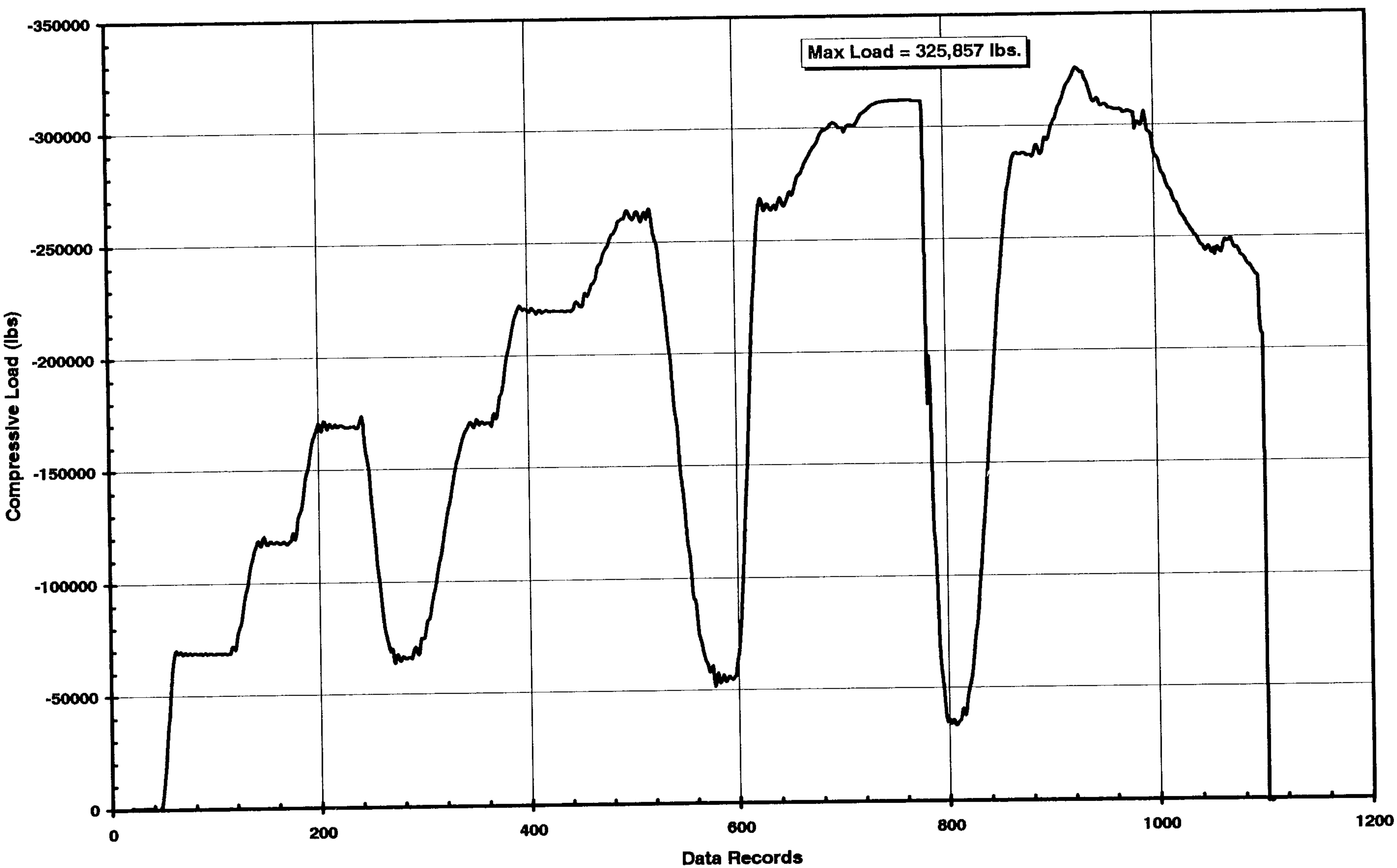
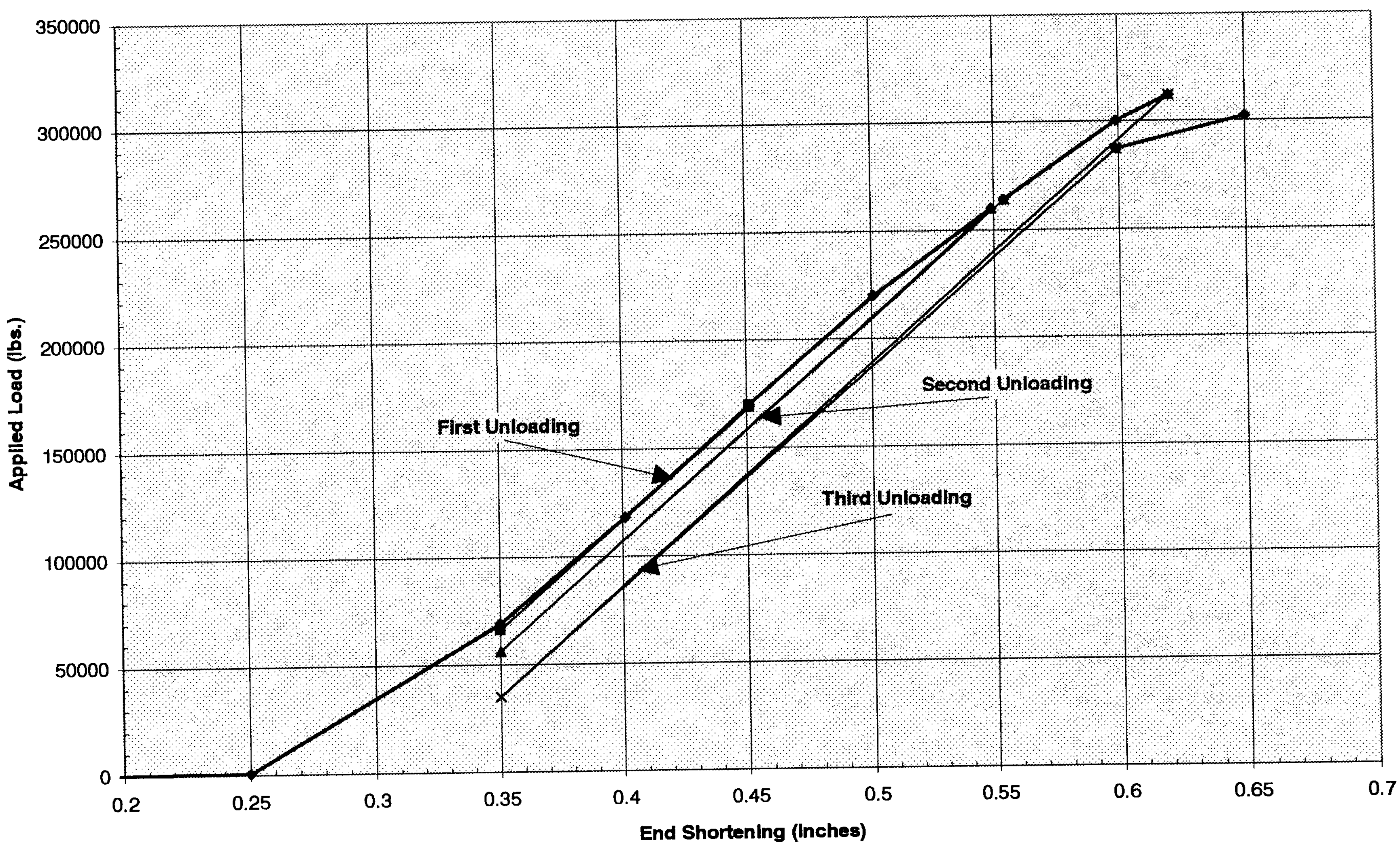
		Pre-Test Survey	A-76 thru A-77
		Post-Test Survey	A-78 thru A-79
		Strain vs. Applied Load	A-80 thru A-98
Axial and Lateral	0695	Load History	A-99
		Load vs. End Shortening	A-100
		Pre-Test Survey	A-101 thru A-102
		Post-Test Survey	A-103 thru A-104
		Strain vs. Applied Load	A-105 thru A-123
Axial and Lateral	0995	Load History	A-124
		Load vs. End Shortening	A-125
		Pre-Test Survey	A-126 thru A-127
		Post-Test Survey	A-128 thru A-129
		Strain vs. Applied Load	A-130 thru A-148

Specimen 0494 Axial Load

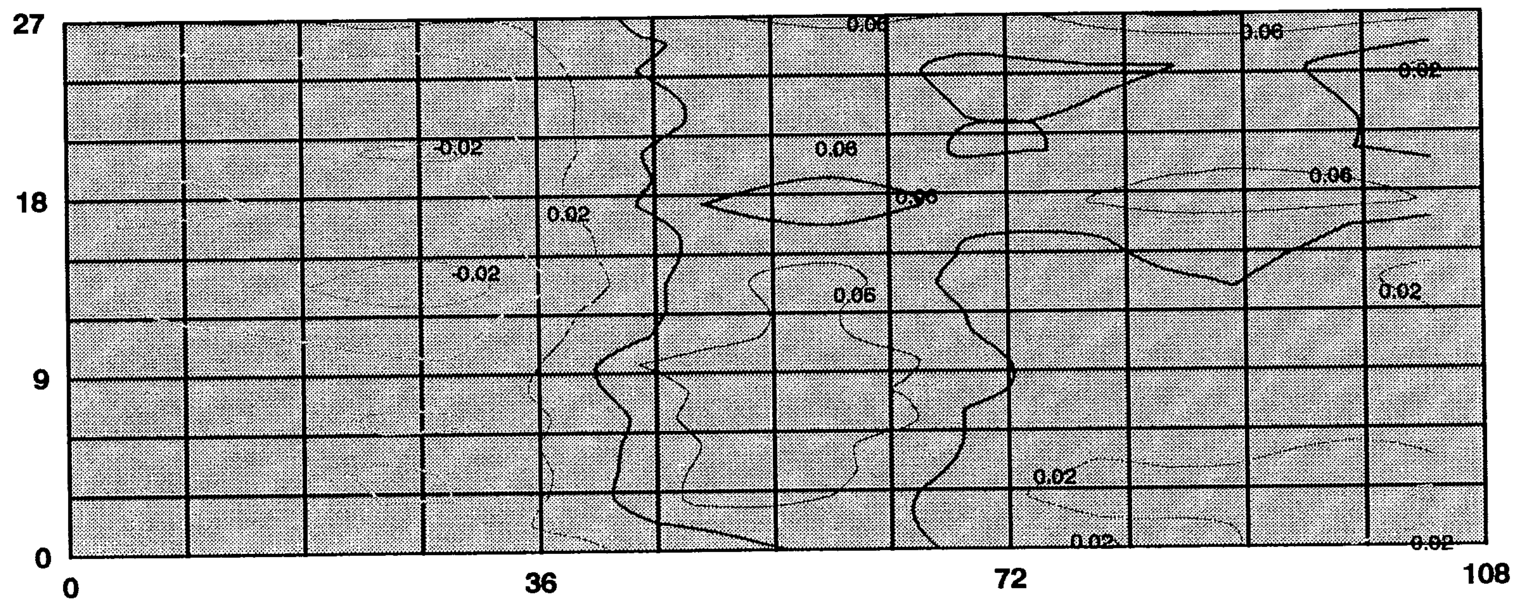
Load History



Load vs. End Shortening



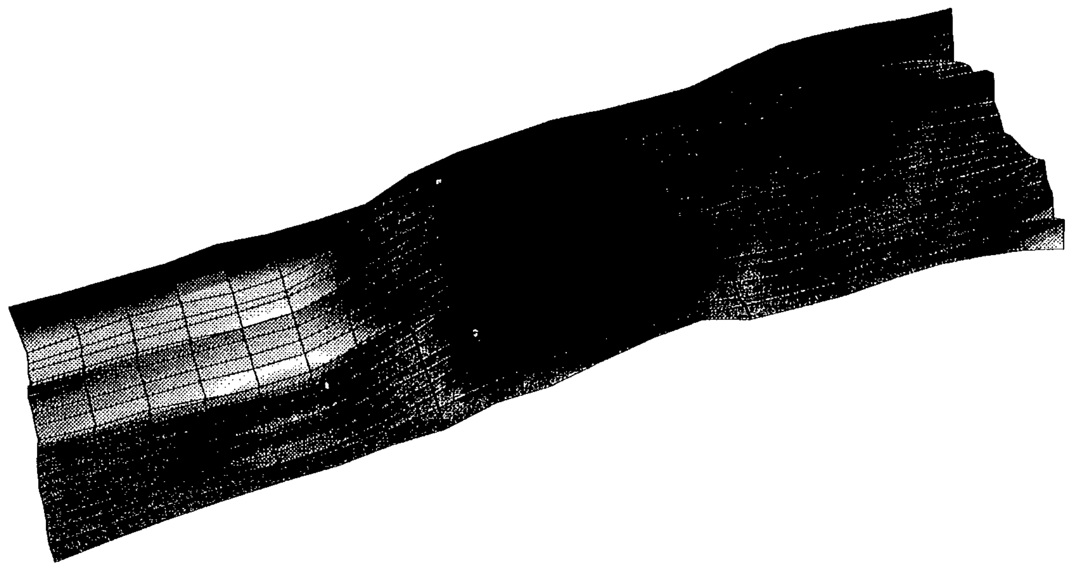
Pre-Test Survey



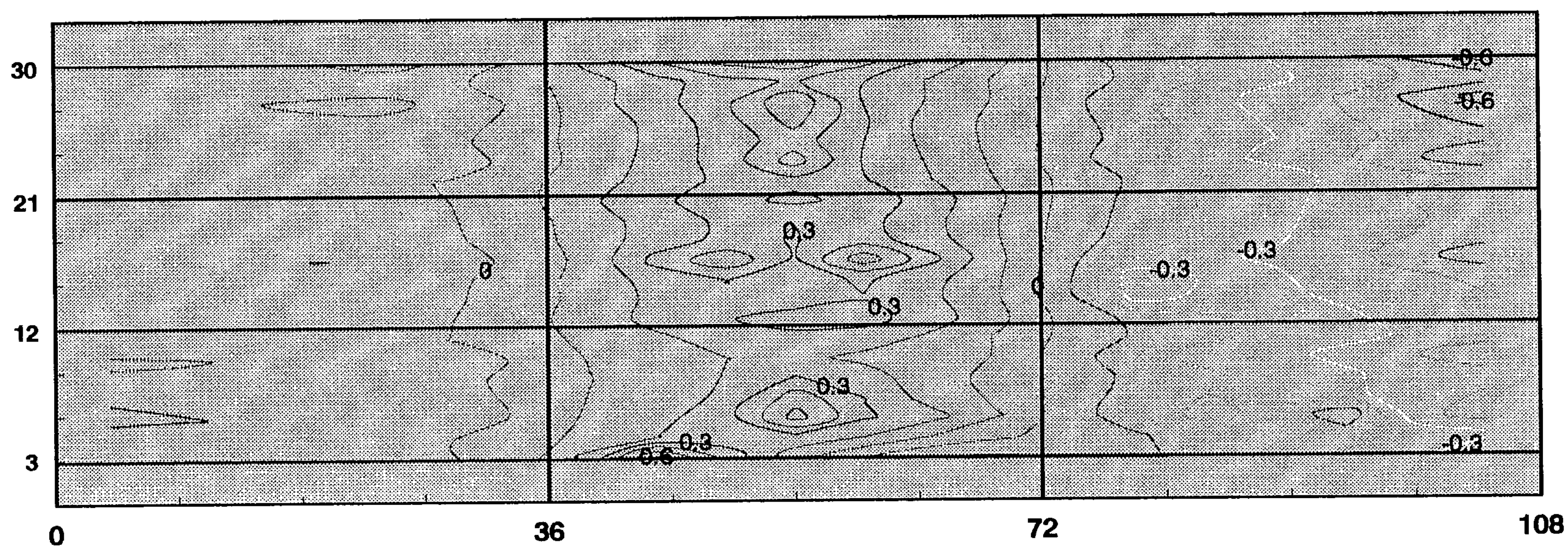
0.0725+	0.0324 to 0.0425	-0.0076 to 0.0024
0.0625 to 0.0725	0.0224 to 0.0324	-0.0176 to -0.0076
0.0525 to 0.0625	0.0124 to 0.0224	-0.0276 to -0.0176
0.0425 to 0.0525	0.0024 to 0.0124	-0.0376 to -0.0276

All measurements are in inches

Pre-Test Survey



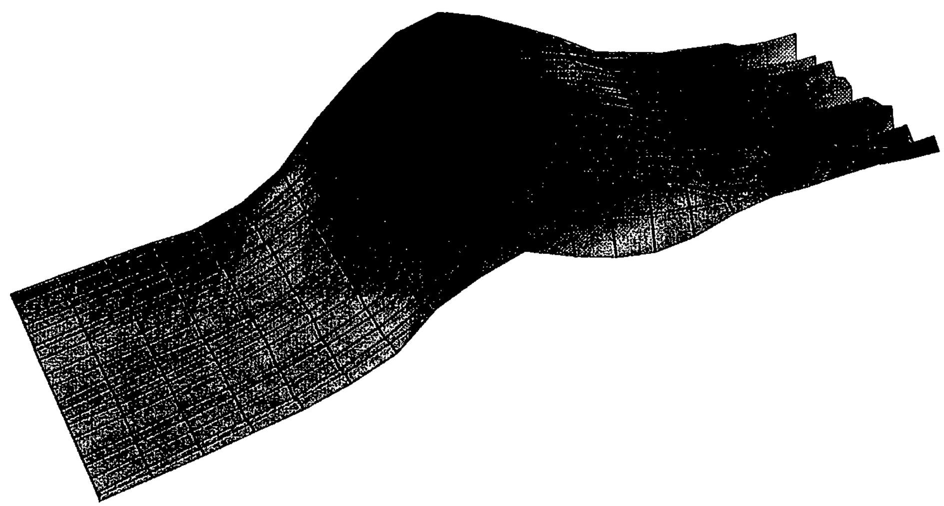
Post-Test Survey

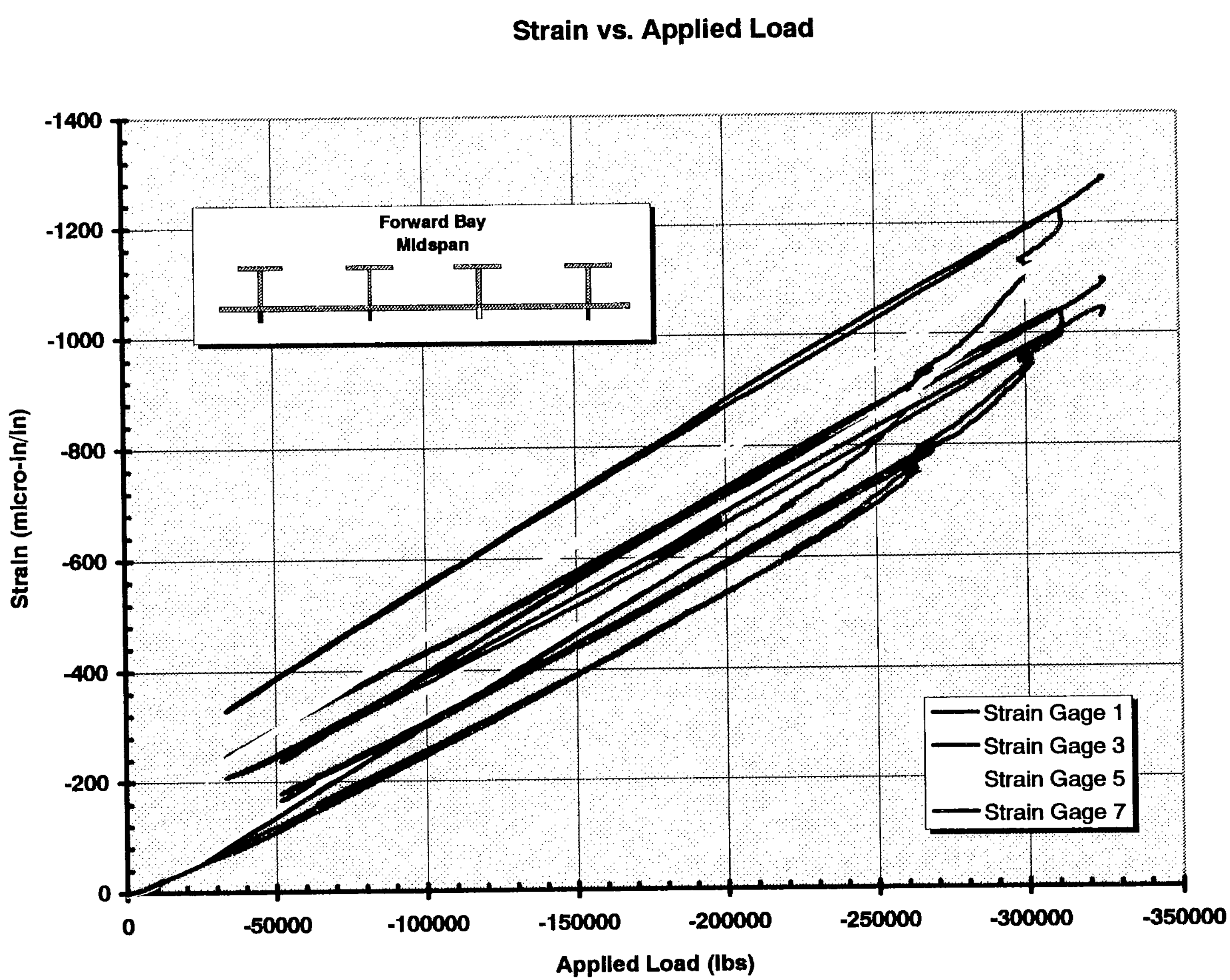


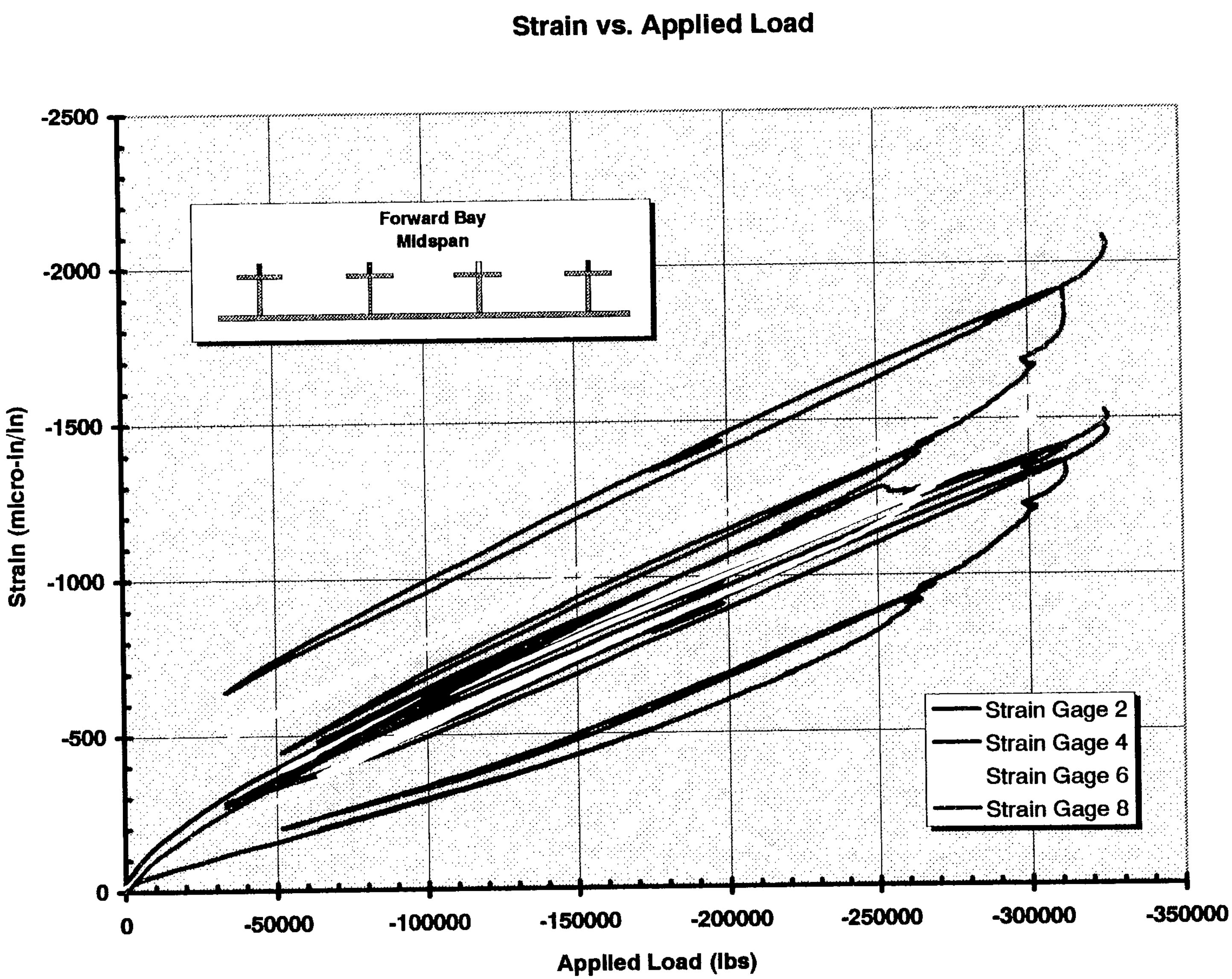
0.6000+	0.1636 to 0.2727	-0.2727 to -0.1636
0.4909 to 0.6000	0.0545 to 0.1636	-0.3818 to -0.2727
0.3818 to 0.4909	-0.0545 to 0.0545	-0.4909 to -0.3818
0.2727 to 0.3818	-0.1636 to -0.0545	-0.6000 to -0.4909

All measurements are in inches

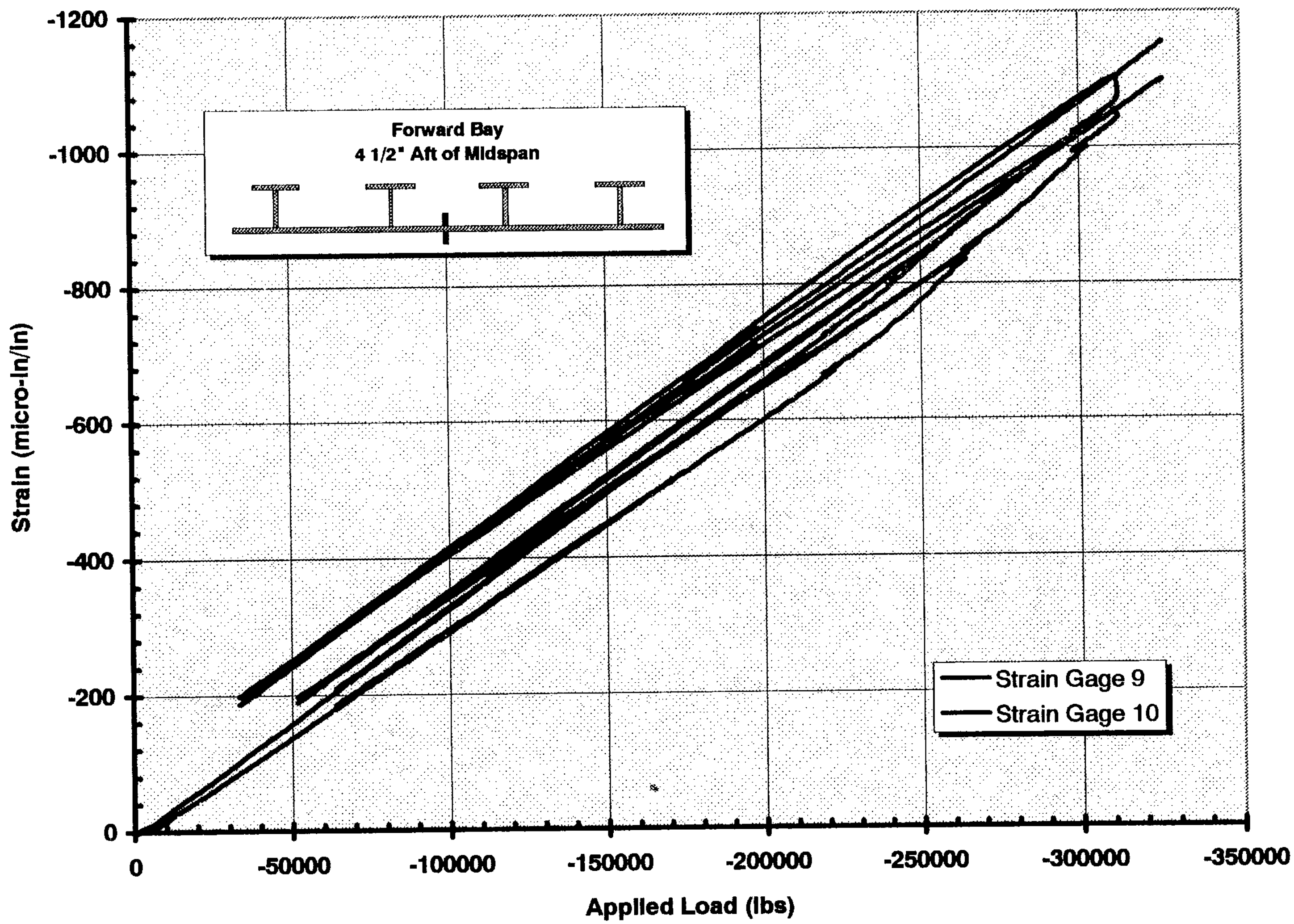
Post-Test Survey



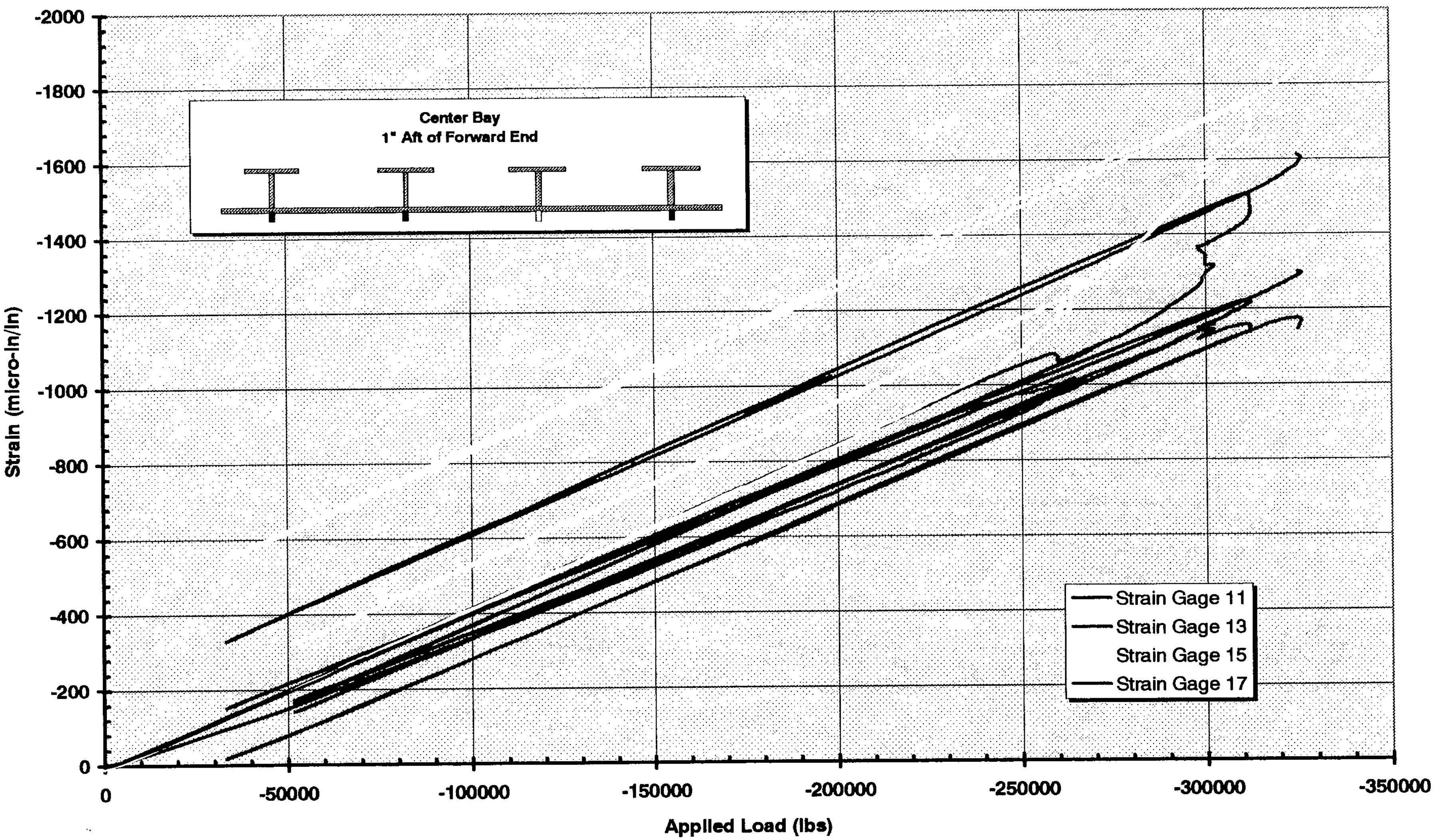

Strain vs. Applied Load
Forward Bay
Midspan
Strain (micro-in/in)
-1400
-1200
-1000
-800
-600
-400
-200
0
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Applied Load (lbs)
Strain Gage 1
Strain Gage 3
Strain Gage 5
Strain Gage 7

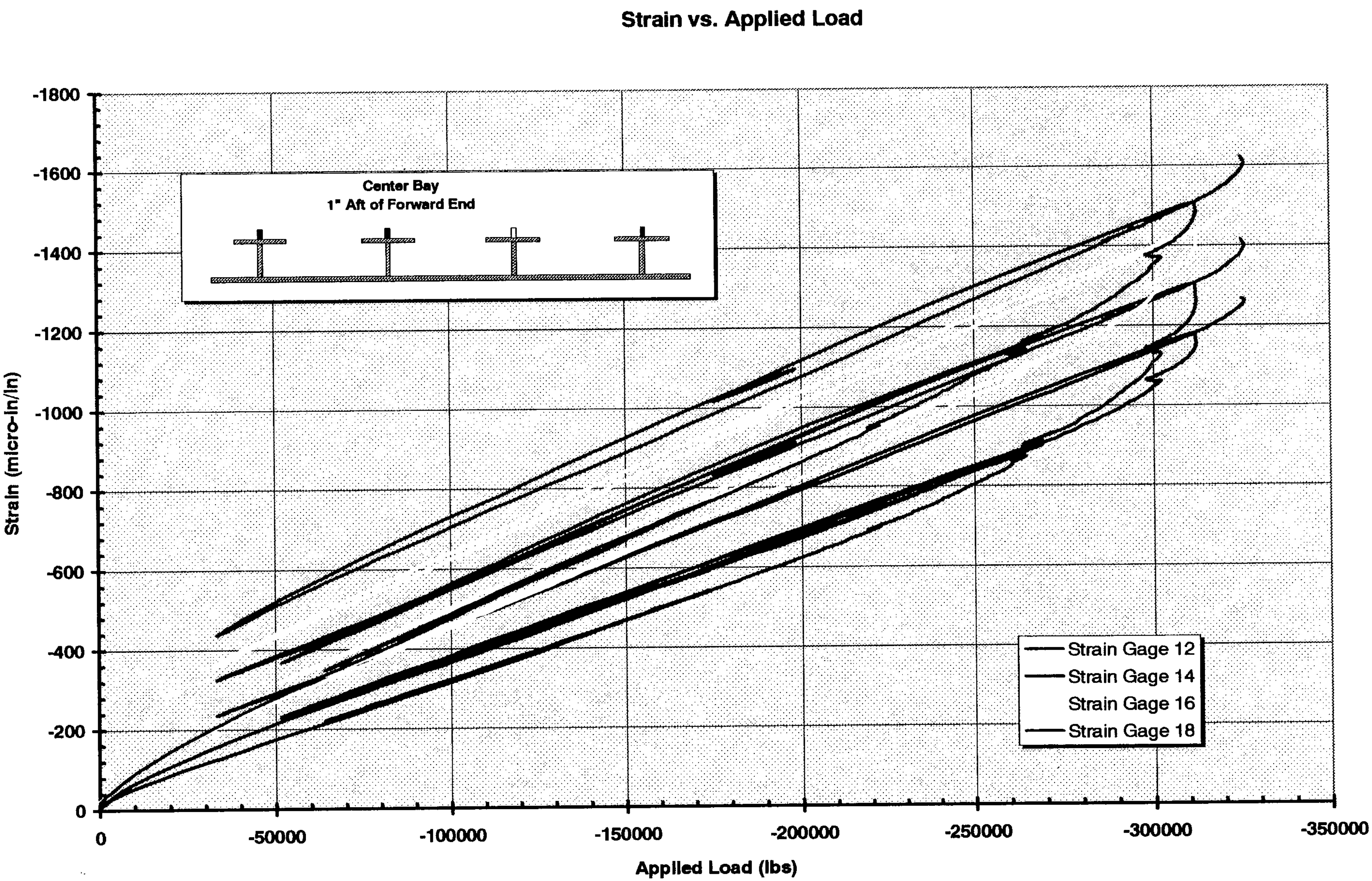

Strain vs. Applied Load
Forward Bay
Midspan
Strain (micro-in/in)
-2500
-2000
-1500
-1000
-500
0
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Applied Load (lbs)
Strain Gage 2
Strain Gage 4
Strain Gage 6
Strain Gage 8

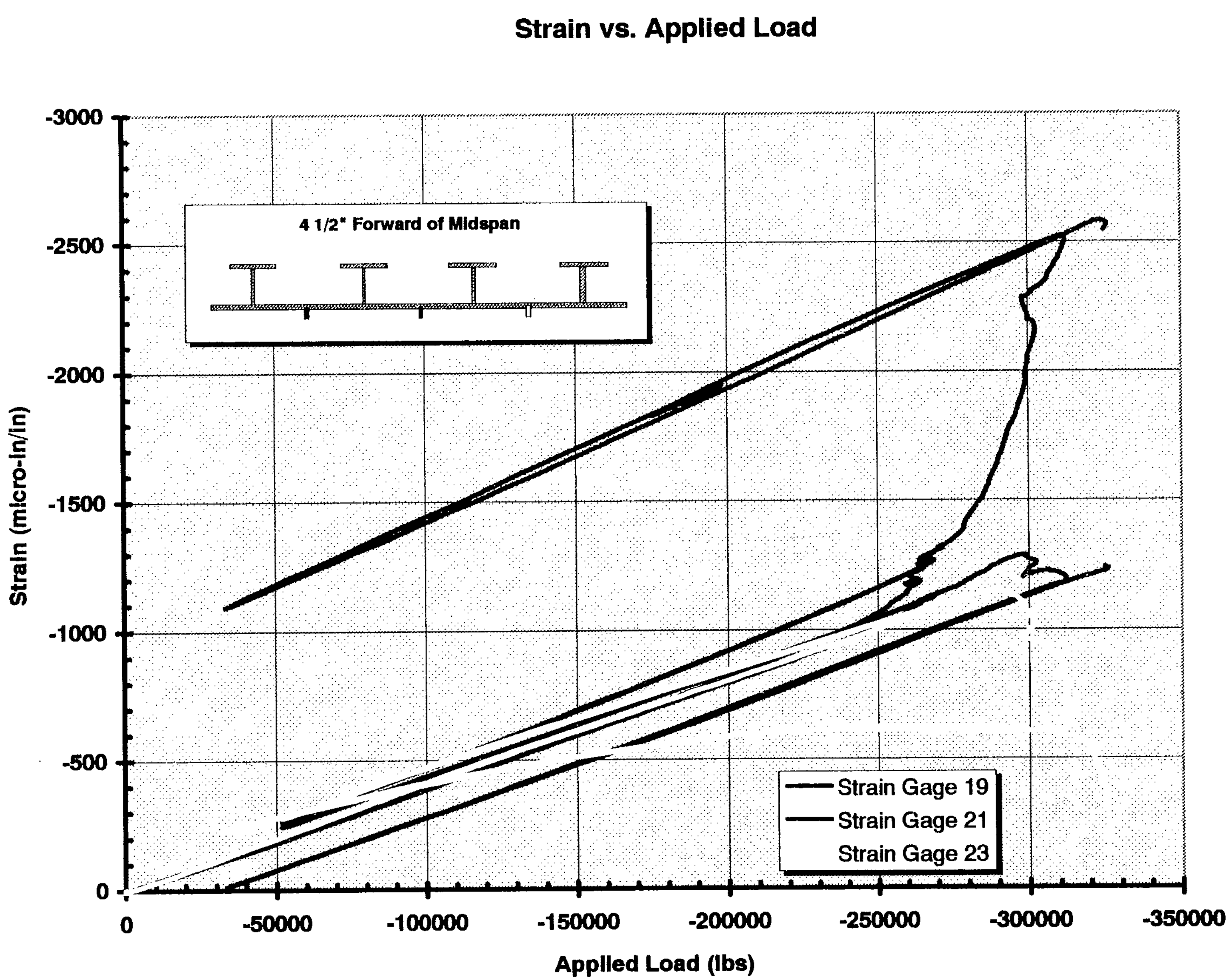
Strain vs. Applied Load

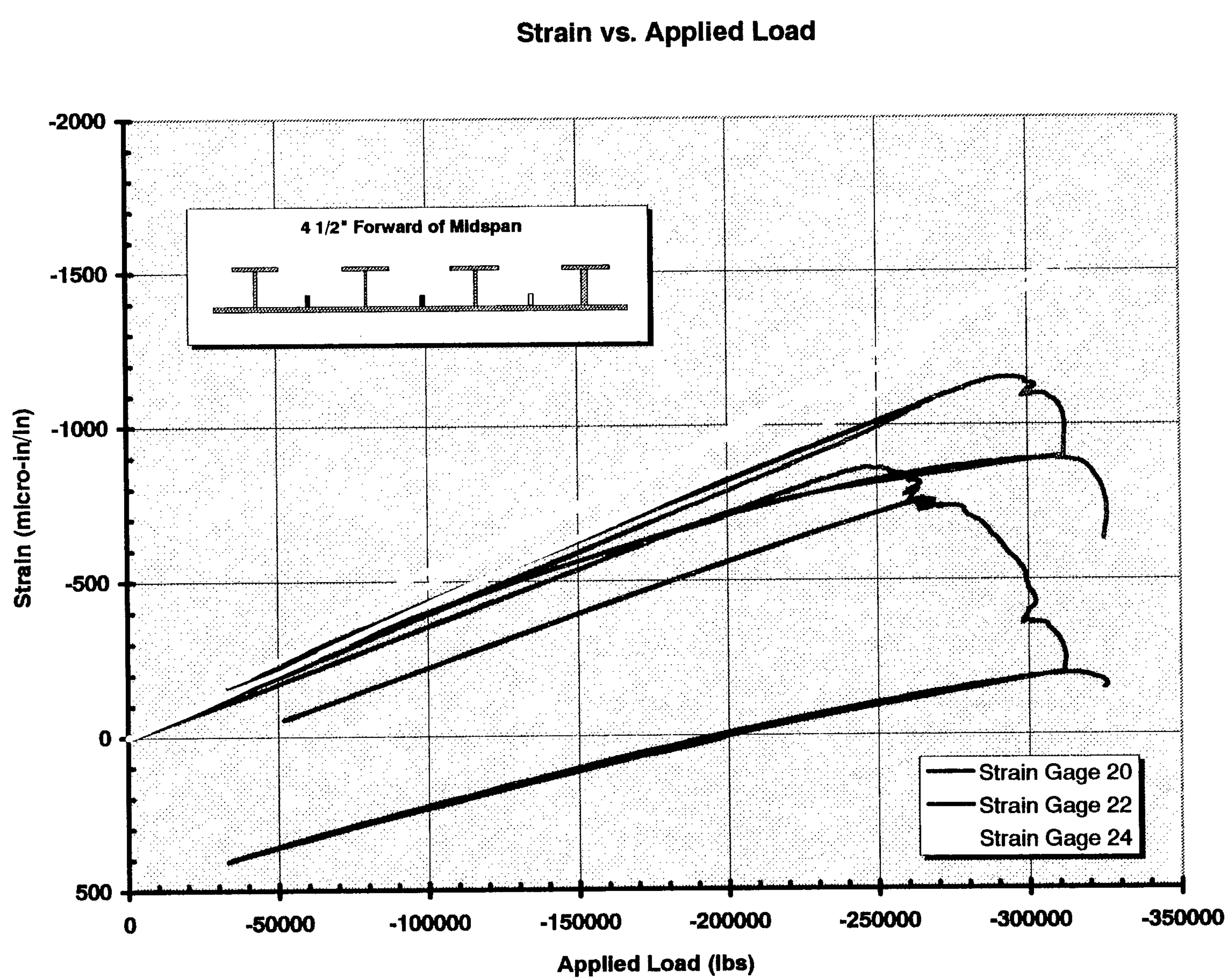


Strain vs. Applied Load

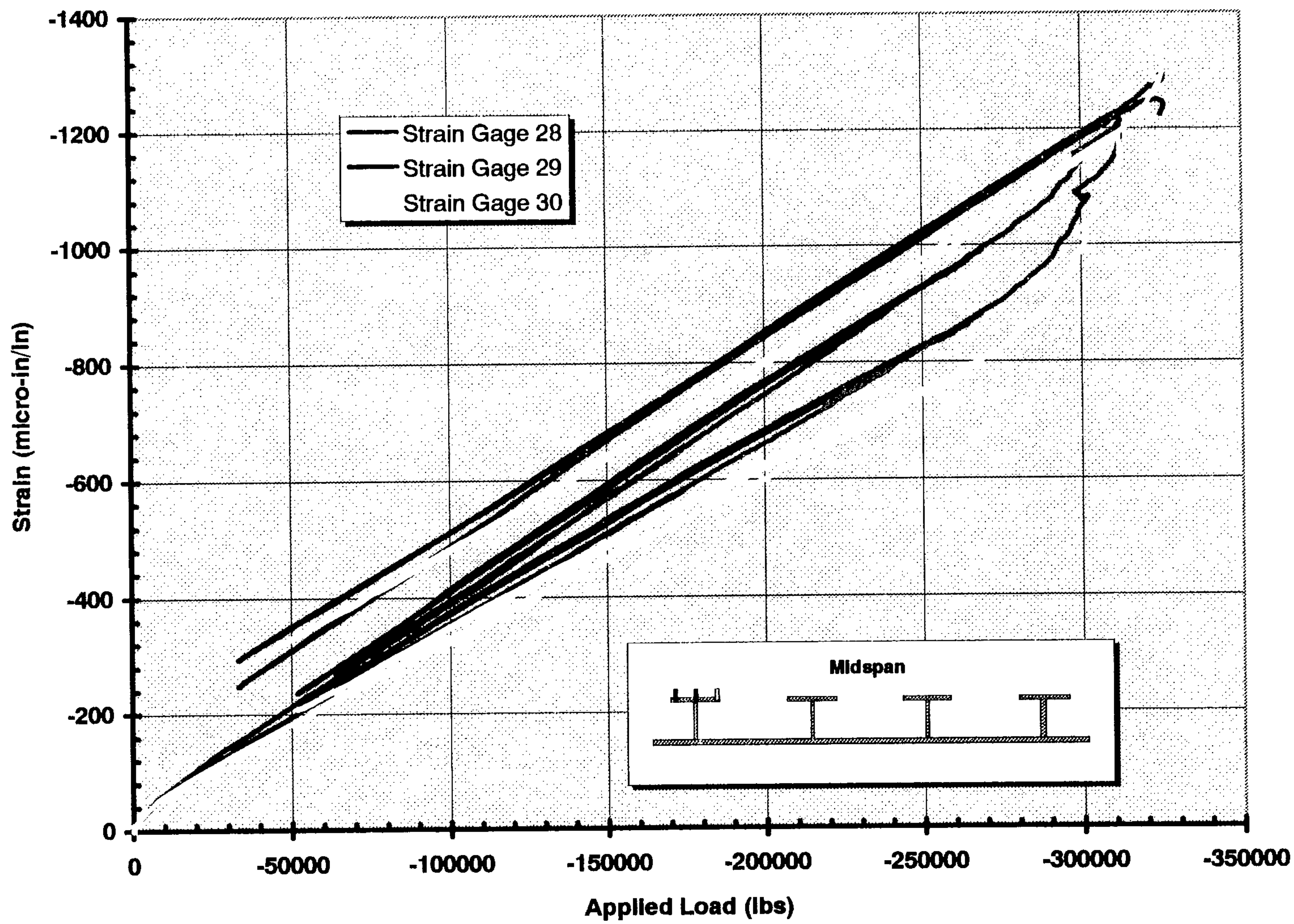



Strain vs. Applied Load
Center Bay
1" Aft of Forward End
Strain (micro-in/in)
-1800
-1600
-1400
-1200
-1000
-800
-600
-400
-200
0
Applied Load (lbs)
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Strain Gage 12
Strain Gage 14
Strain Gage 16
Strain Gage 18

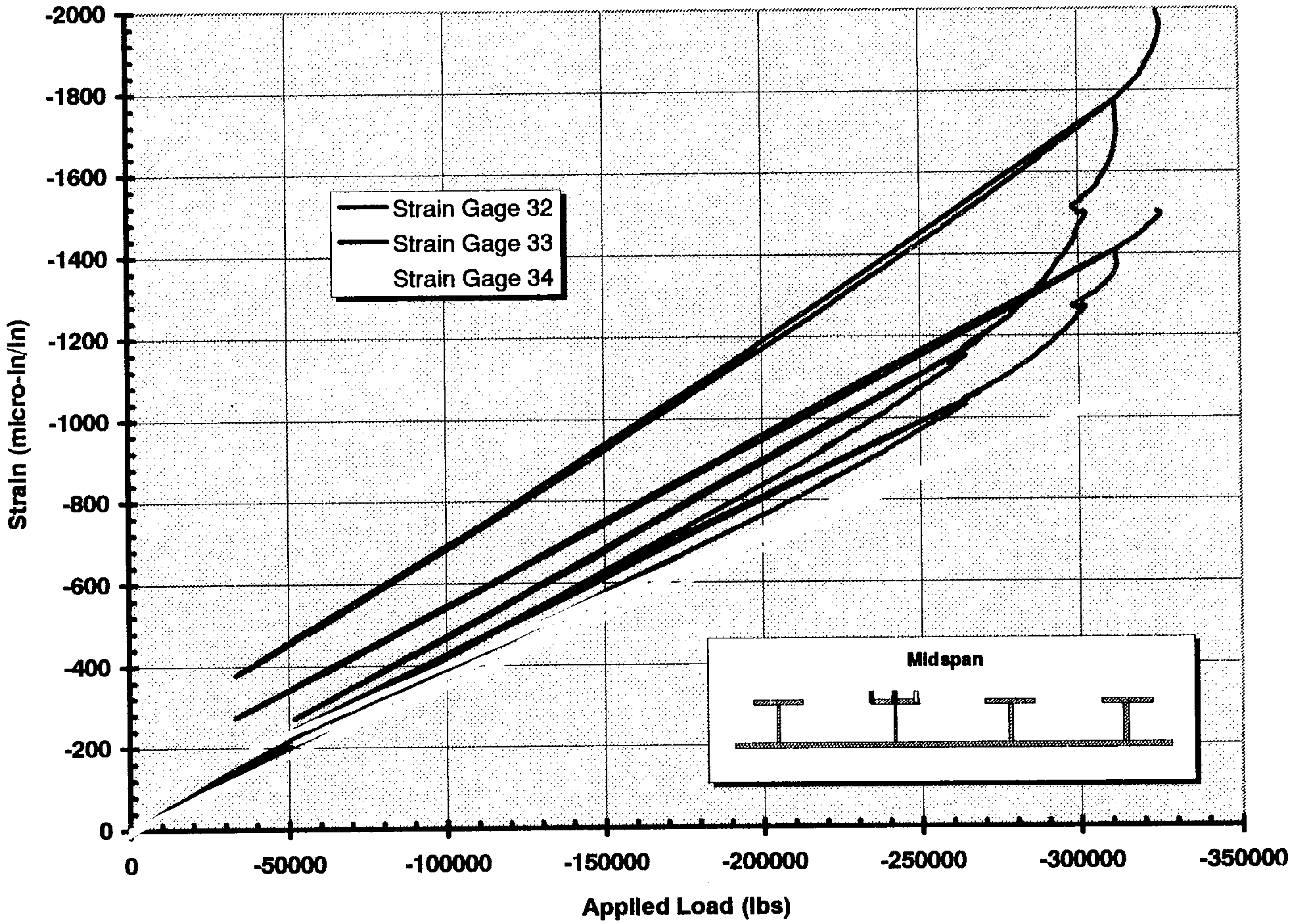

Strain vs. Applied Load
4 1/2" Forward of Midspan
Strain (micro-in/in)
-3000
-2500
-2000
-1500
-1000
-500
0
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Applied Load (lbs)
Strain Gage 19
Strain Gage 21
Strain Gage 23


Strain vs. Applied Load
4 1/2" Forward of Midspan
Strain (micro-in/in)
-2000
-1500
-1000
-500
0
500
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Applied Load (lbs)
Strain Gage 20
Strain Gage 22
Strain Gage 24

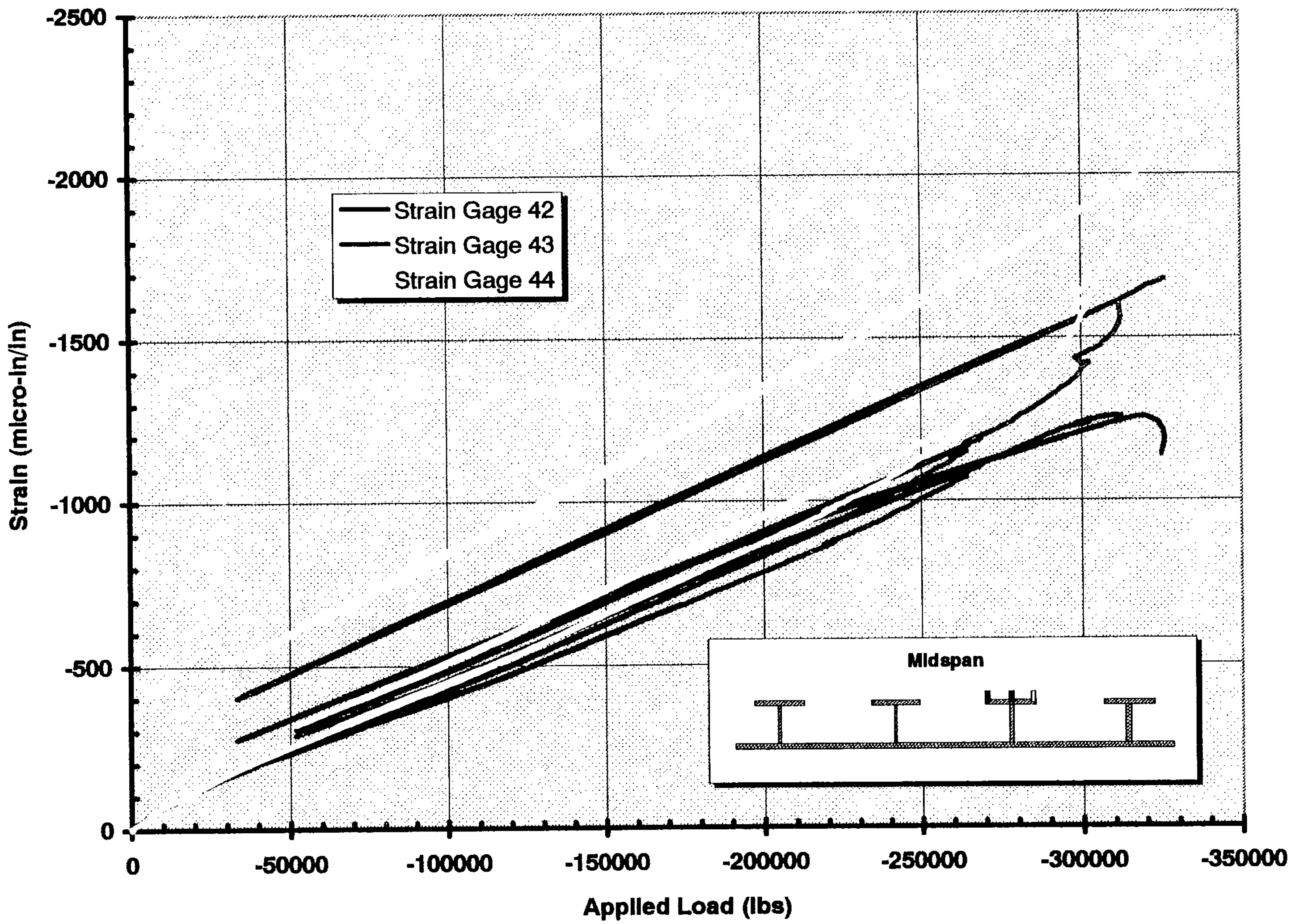
Strain vs. Applied Load



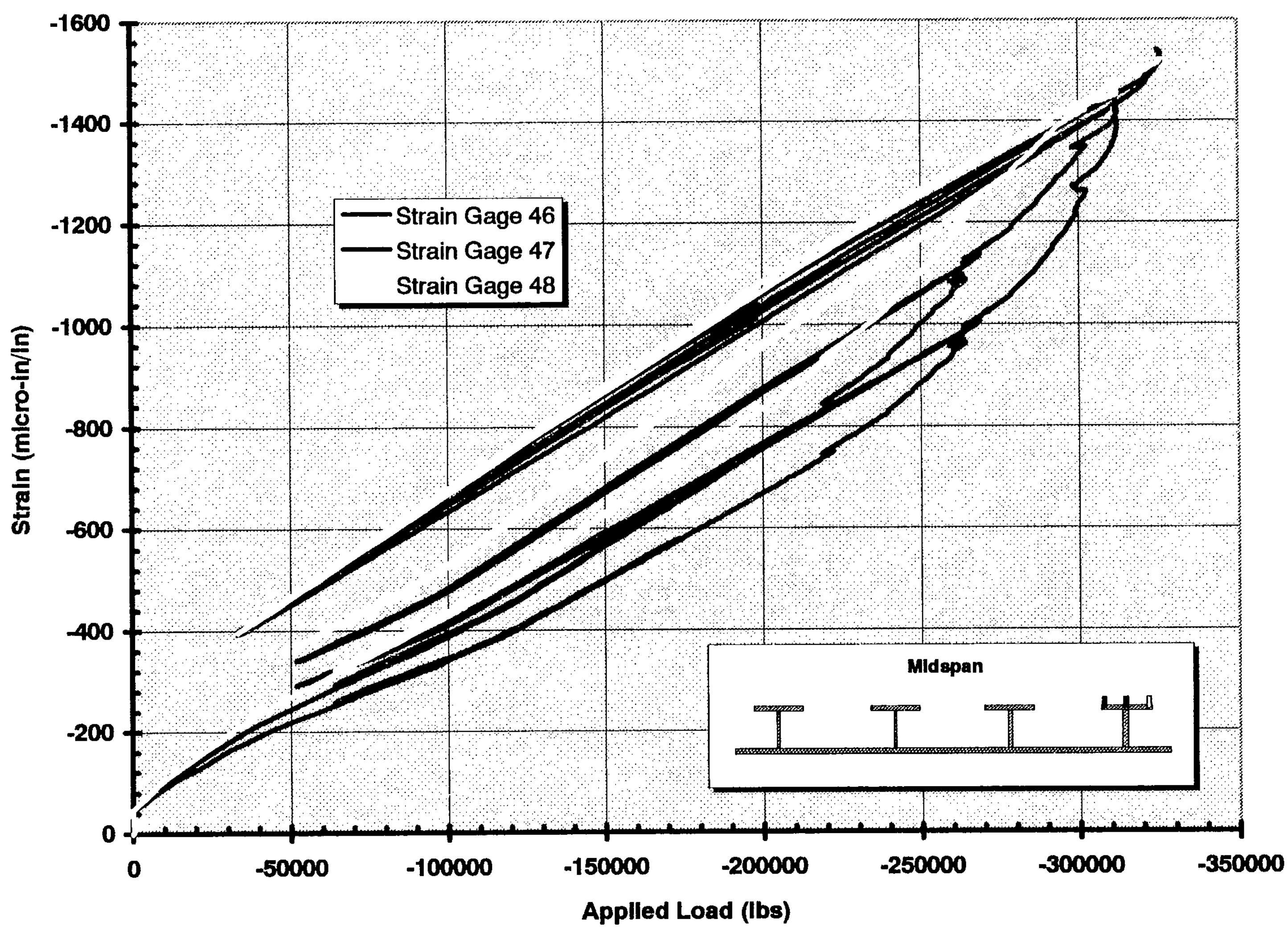
Strain vs. Applied Load

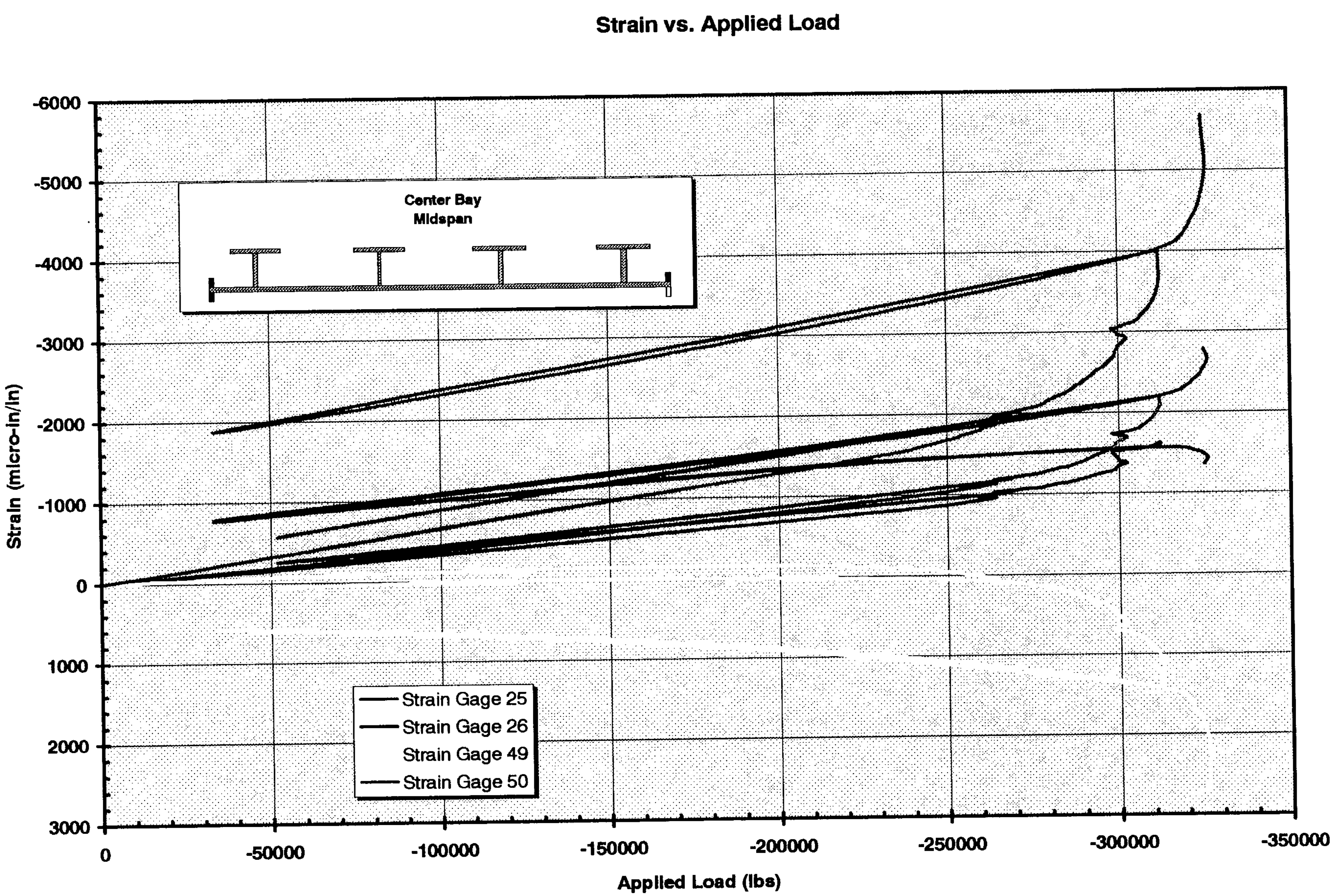


Strain vs. Applied Load

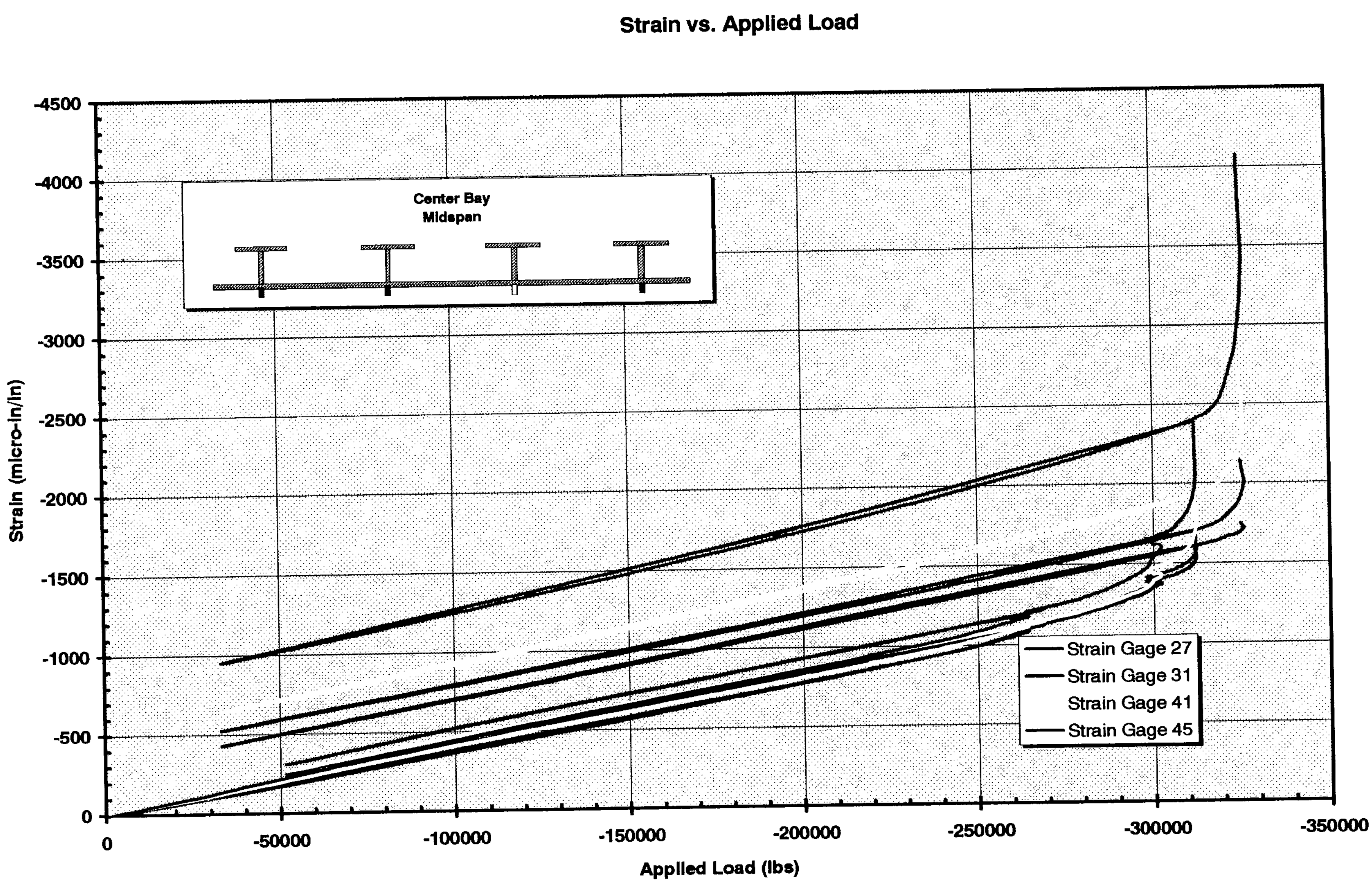


Strain vs. Applied Load

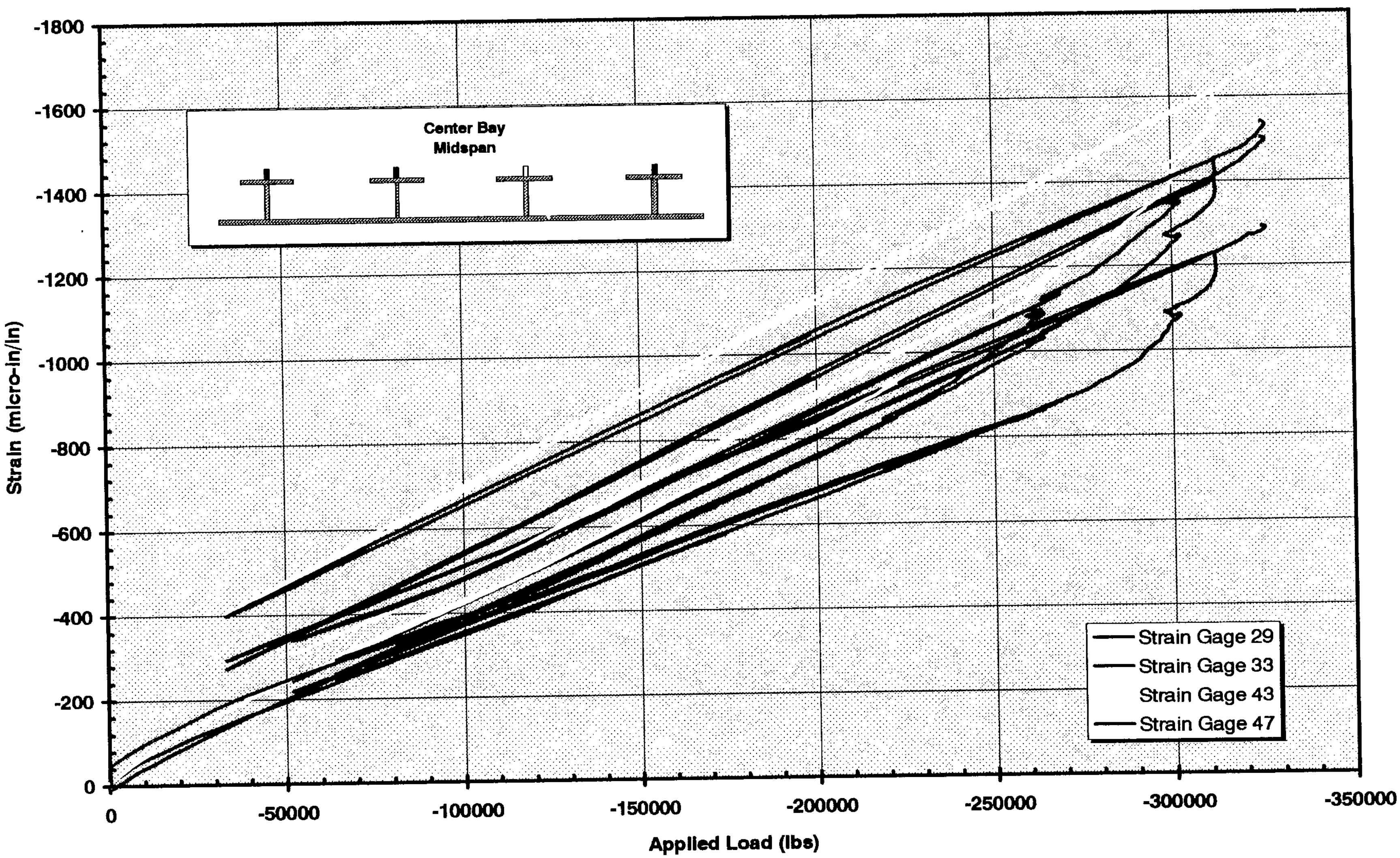




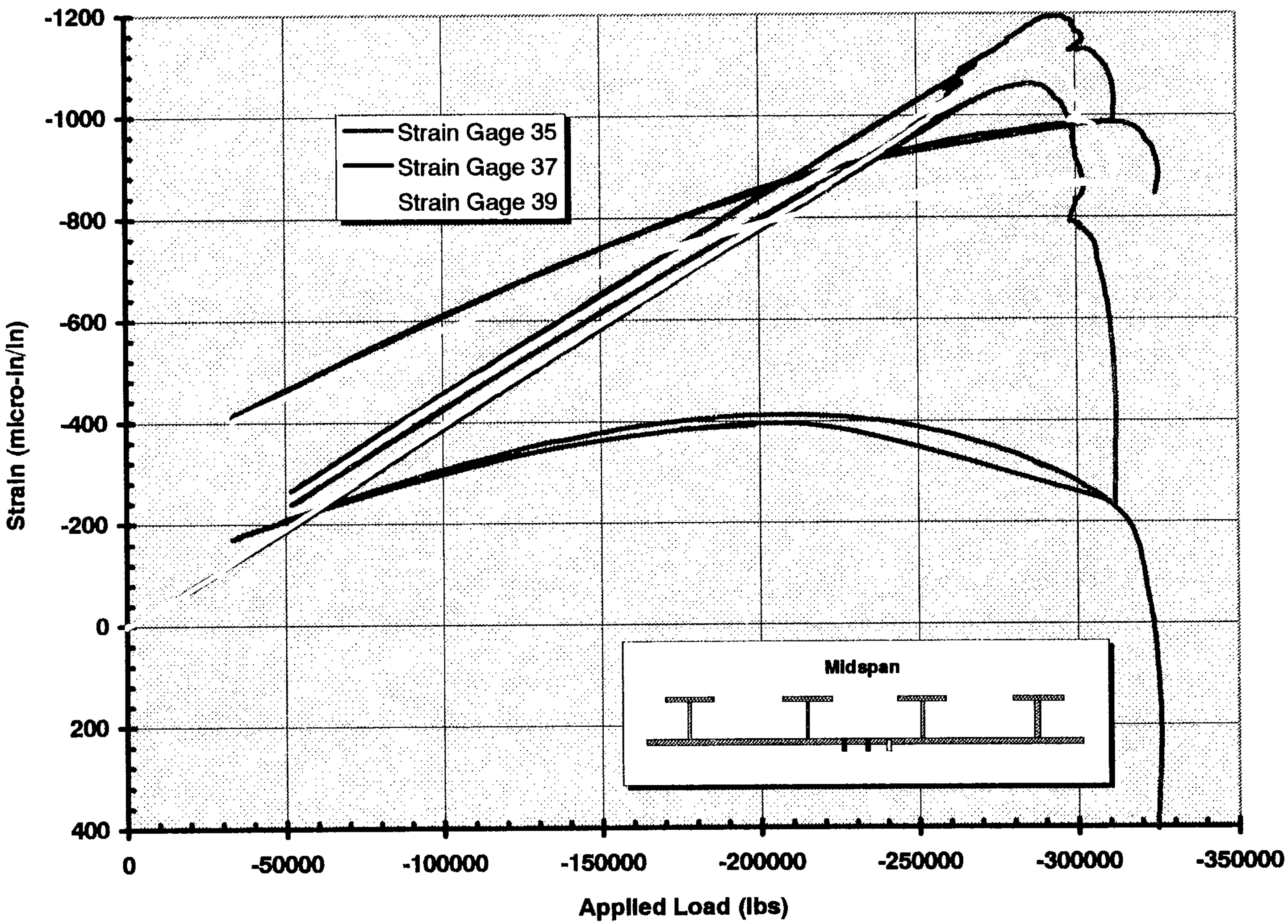
Strain vs. Applied Load
Center Bay
Midspan
Strain Gage 25
Strain Gage 26
Strain Gage 49
Strain Gage 50
Strain (micro-in/in)
-6000
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Applied Load (lbs)


Strain vs. Applied Load
Center Bay
Midspan
Strain (micro-in/in)
-4500
-4000
-3500
-3000
-2500
-2000
-1500
-1000
-500
0
Applied Load (lbs)
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Strain Gage 27
Strain Gage 31
Strain Gage 41
Strain Gage 45

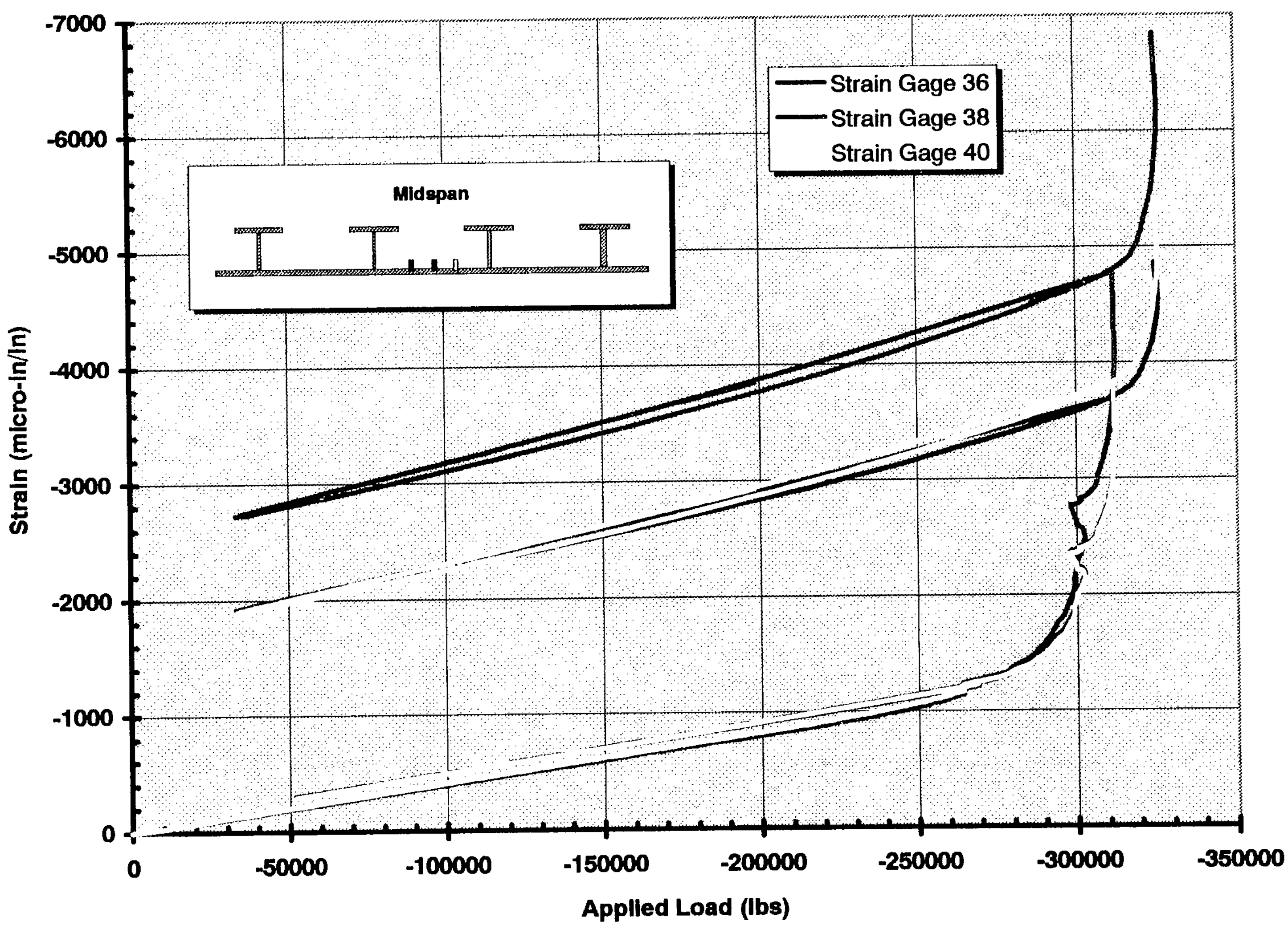
Strain vs. Applied Load



Strain vs. Applied Load

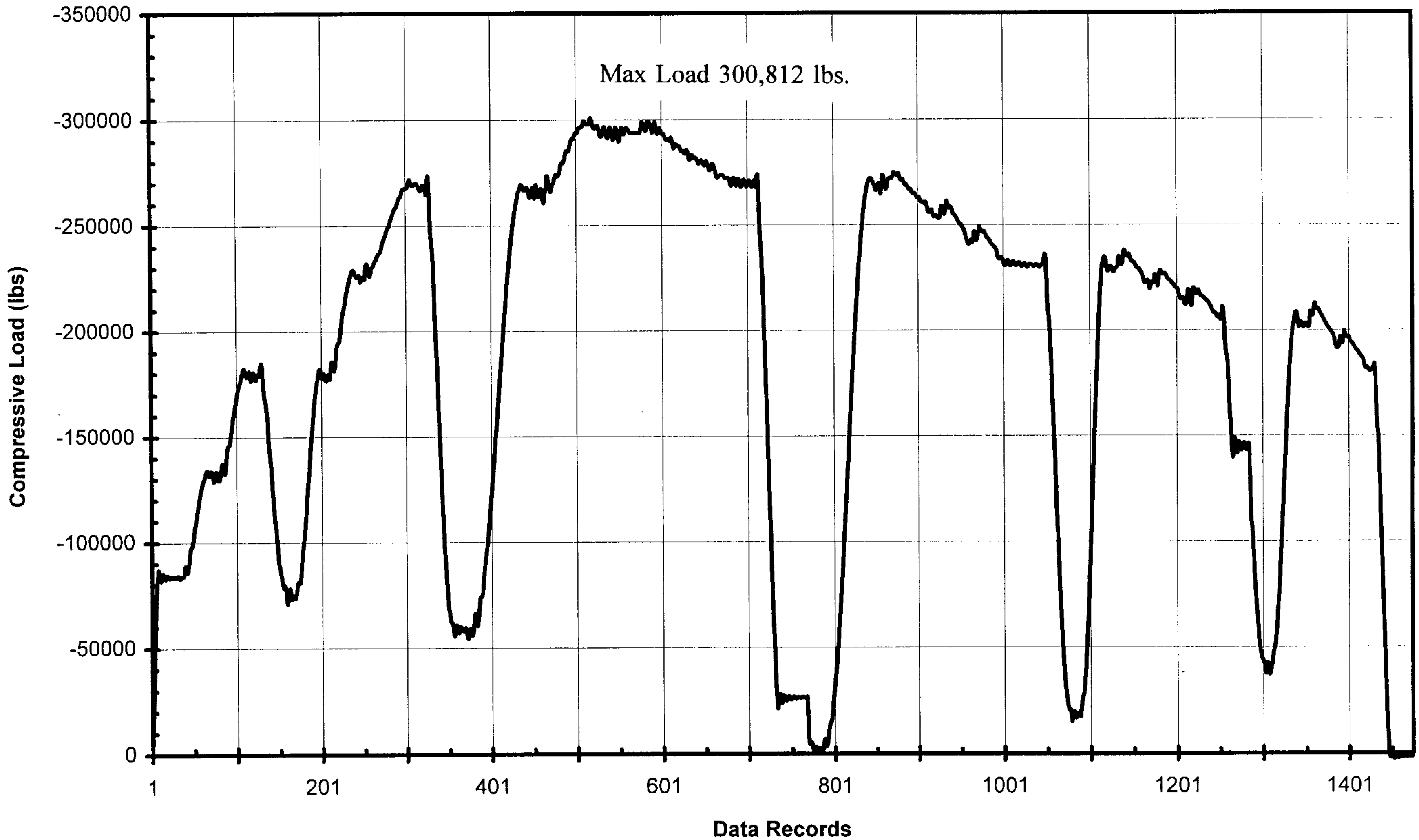


Strain vs. Applied Load

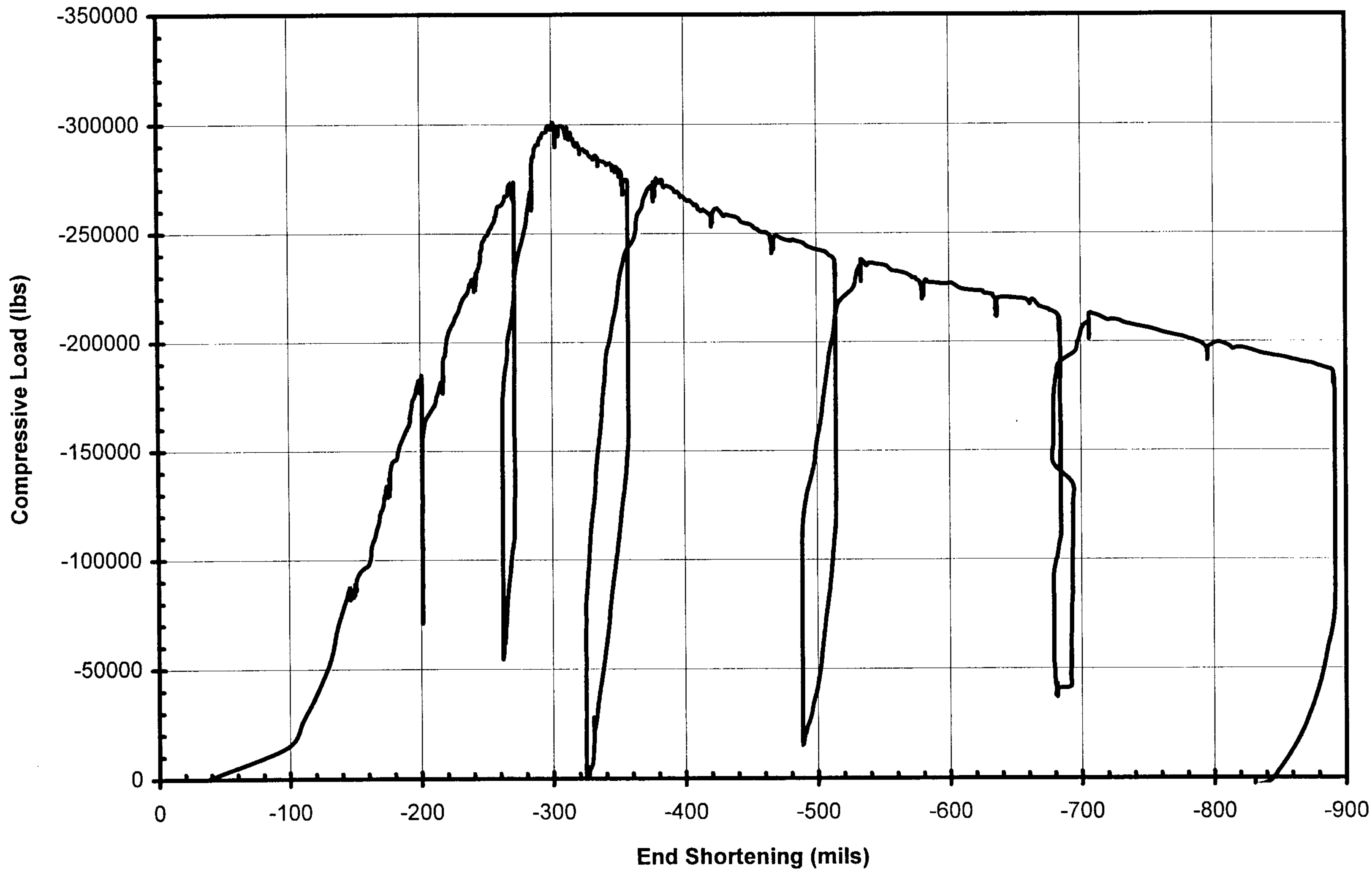


Specimen 0894   Axial Load

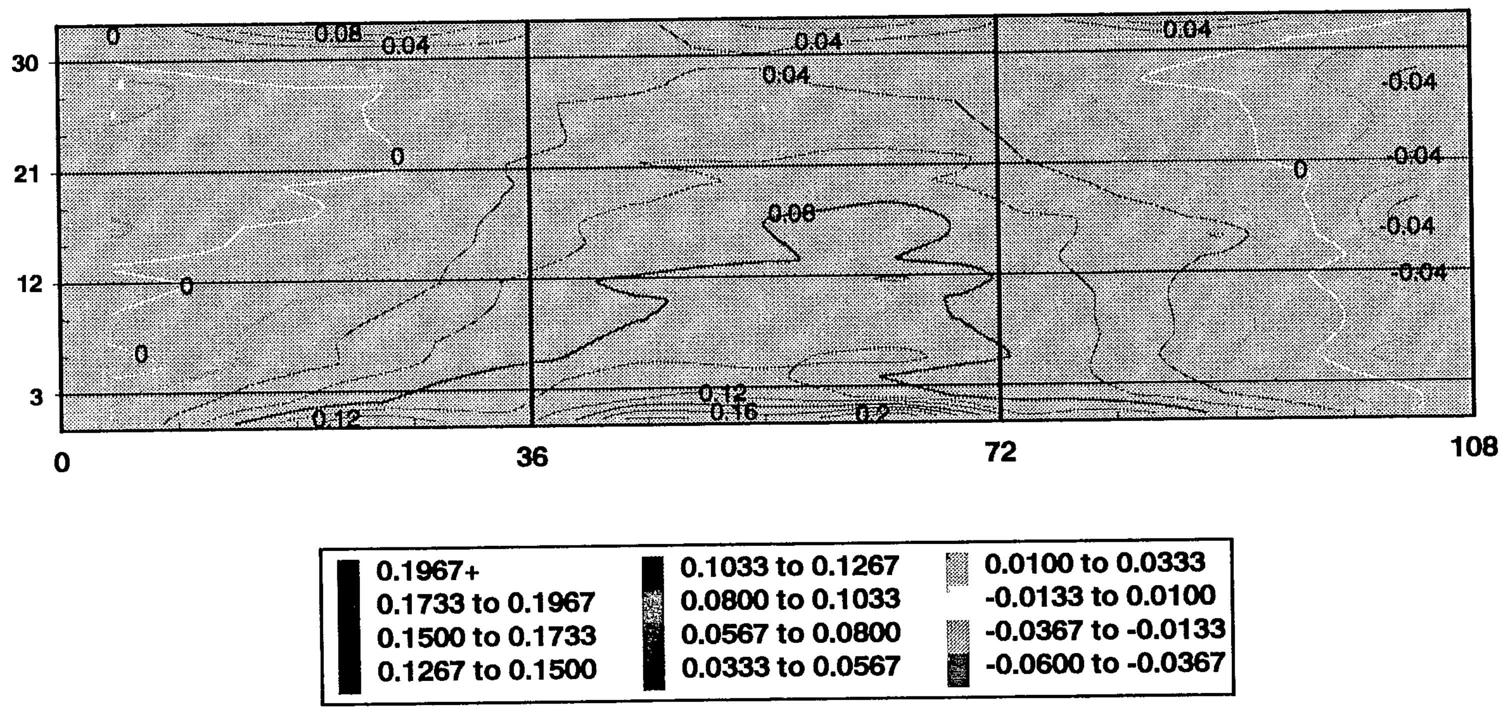
Load History



Load vs. End-Shortening

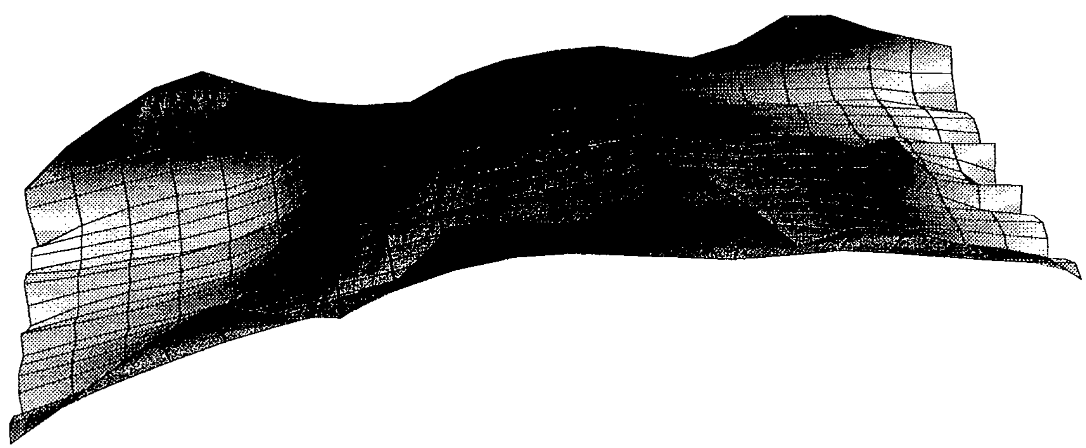


Pre-Test Survey

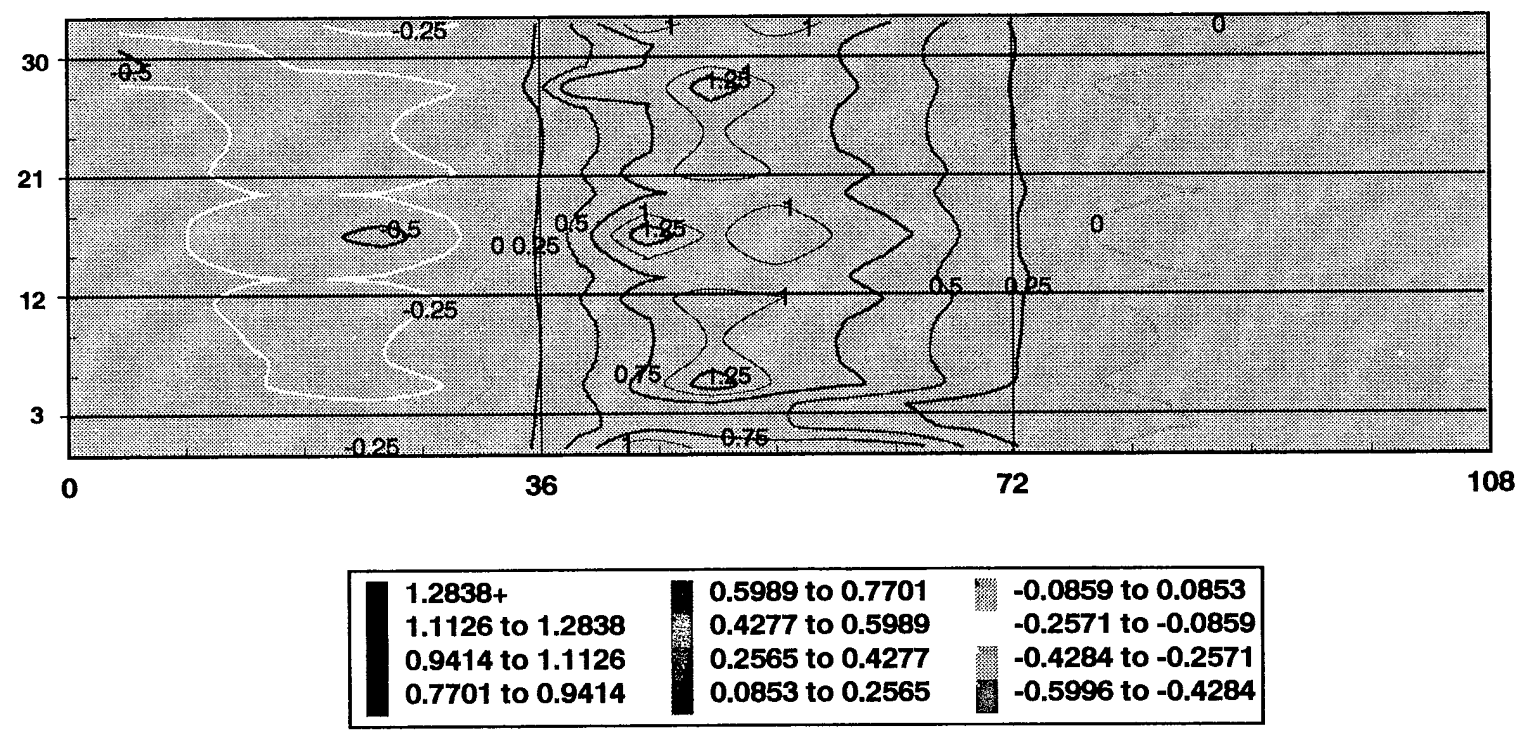


All measurements in Inches

Pre-Test Survey

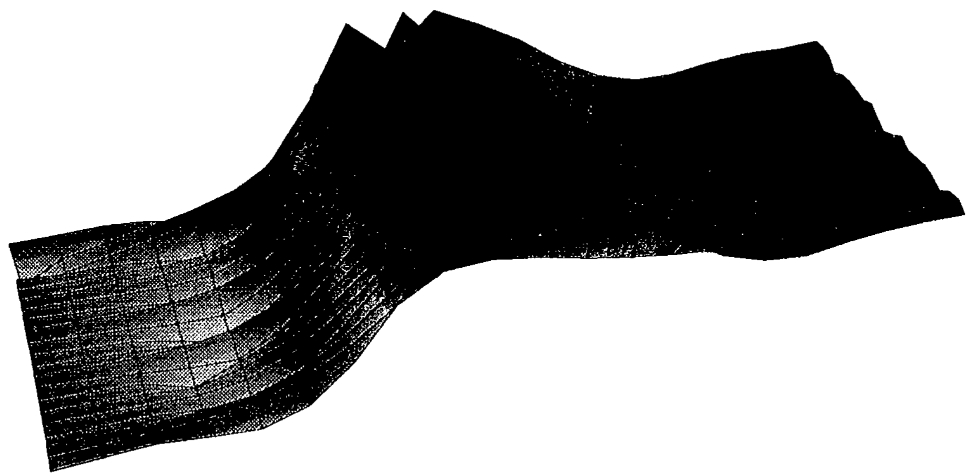


Post-Test Survey

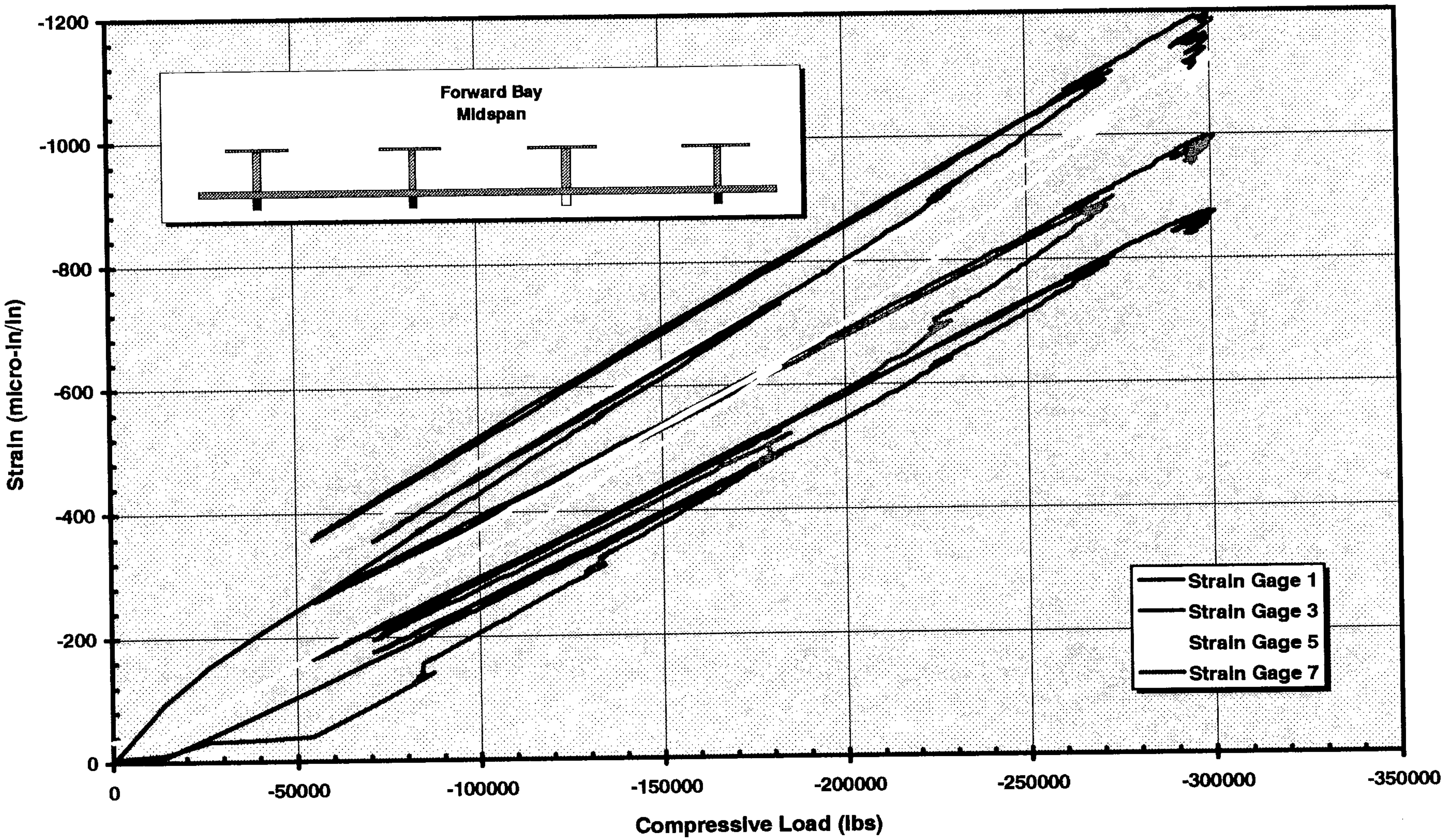


All measurements in inches

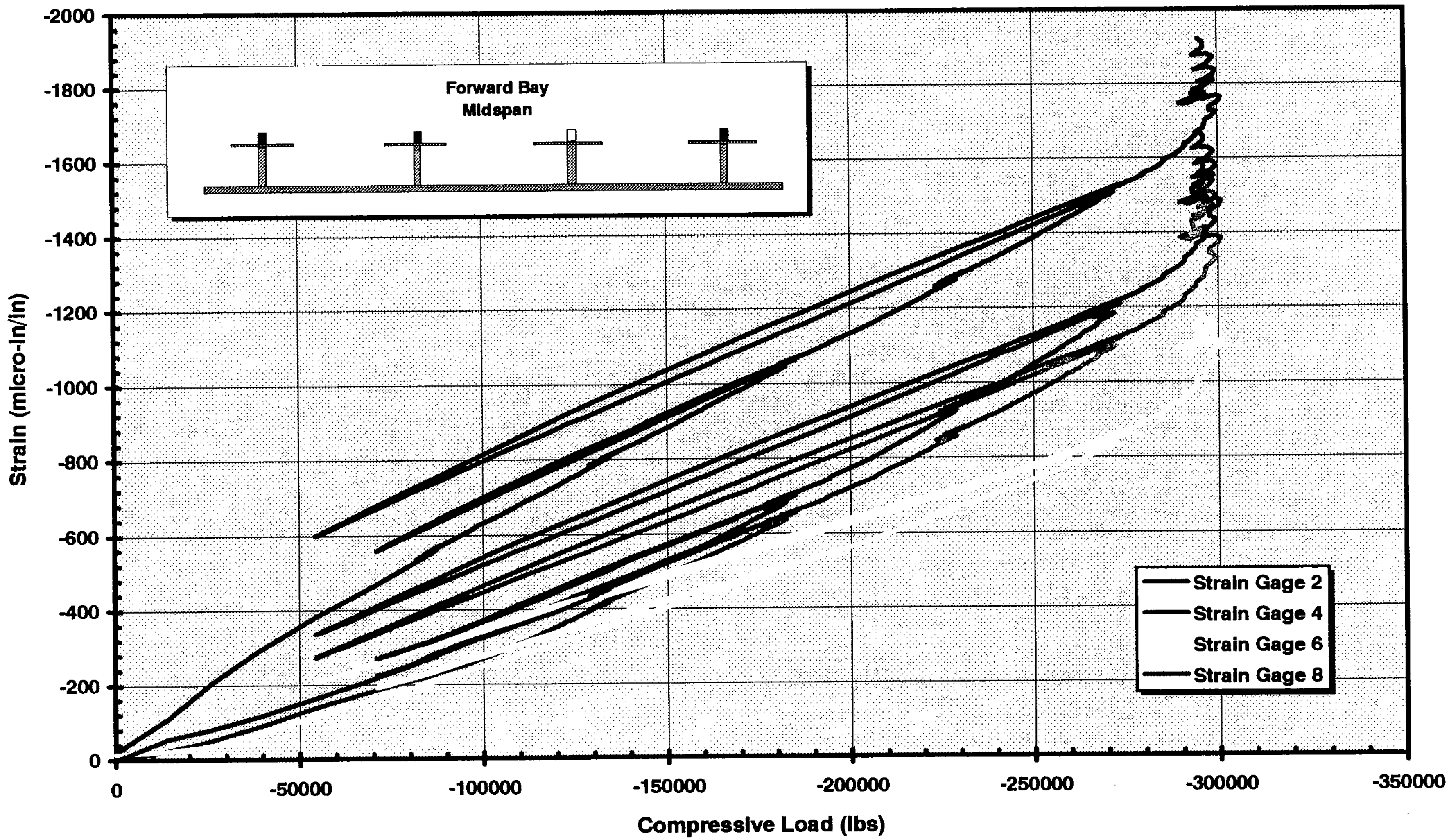
Post-Test Survey

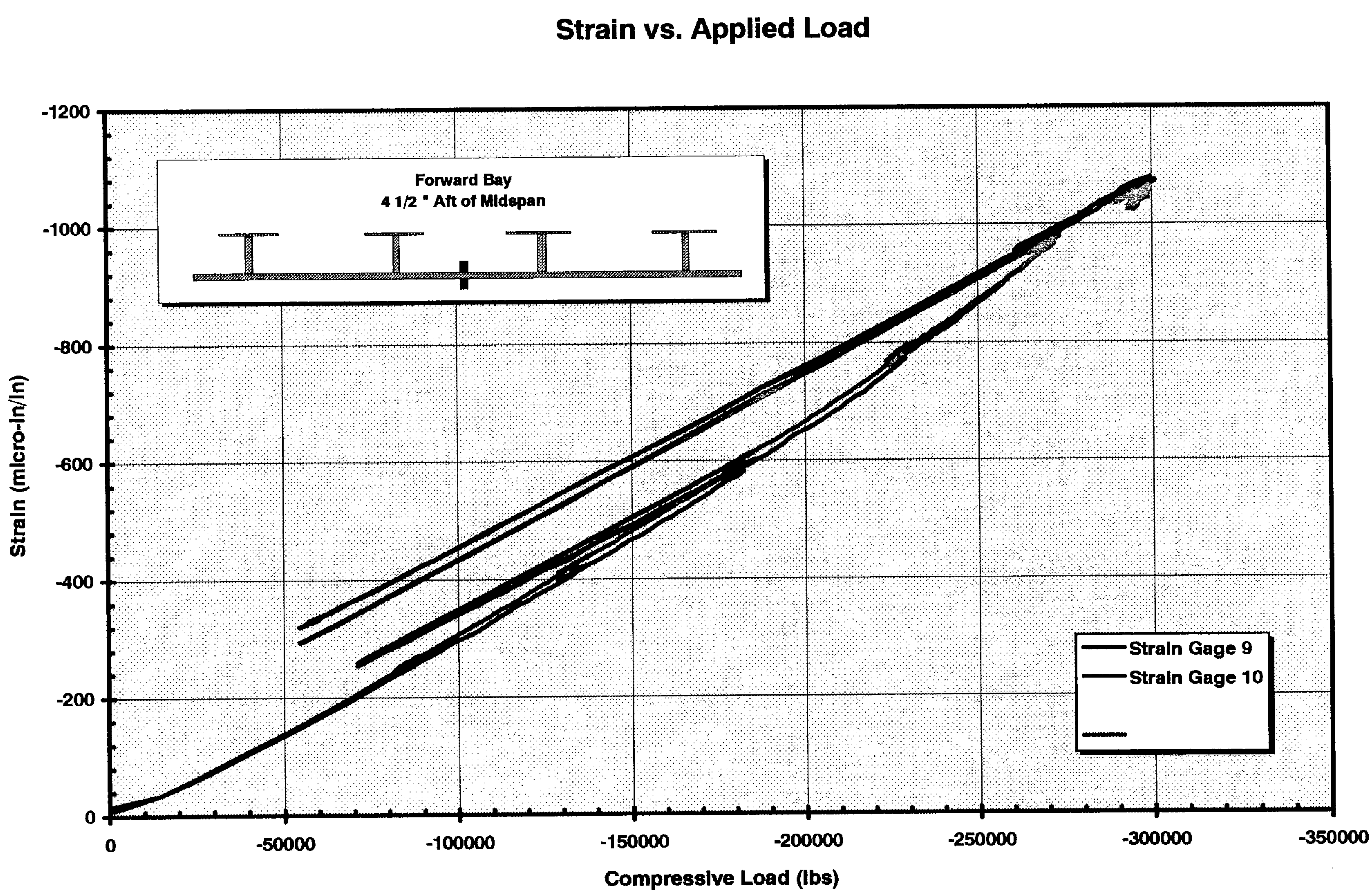


Strain vs. Applied Load

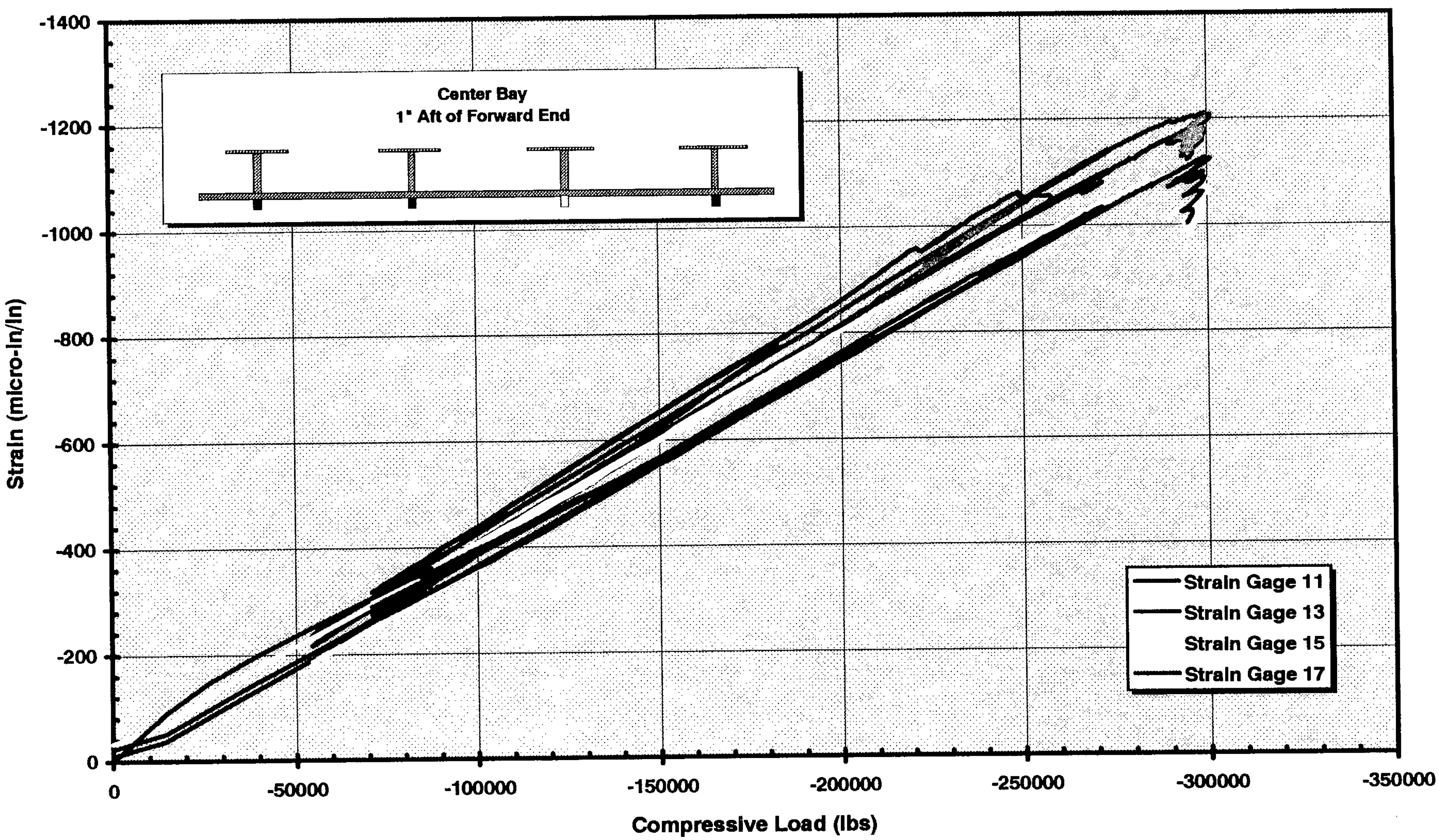


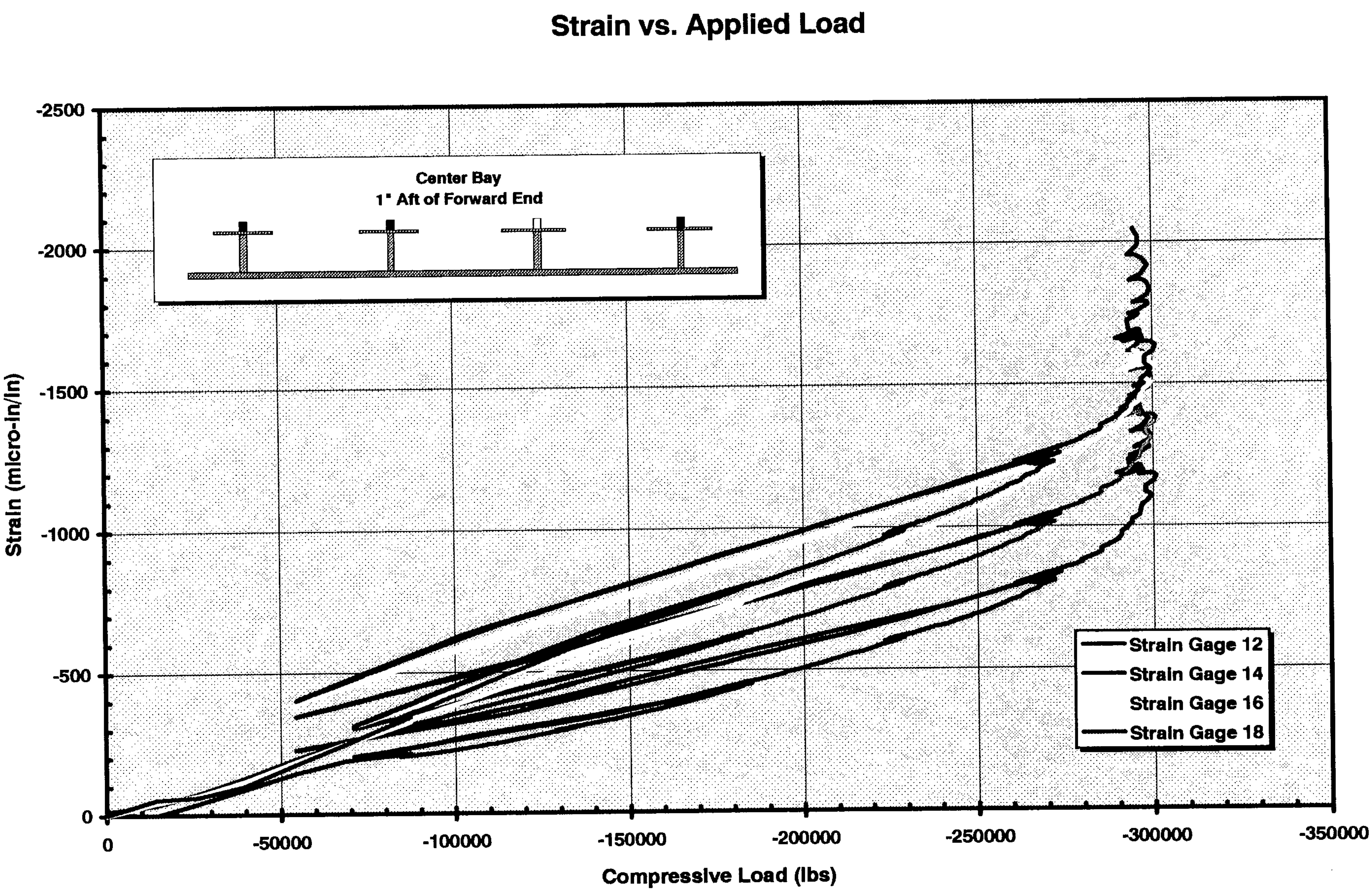
Strain vs. Applied Load



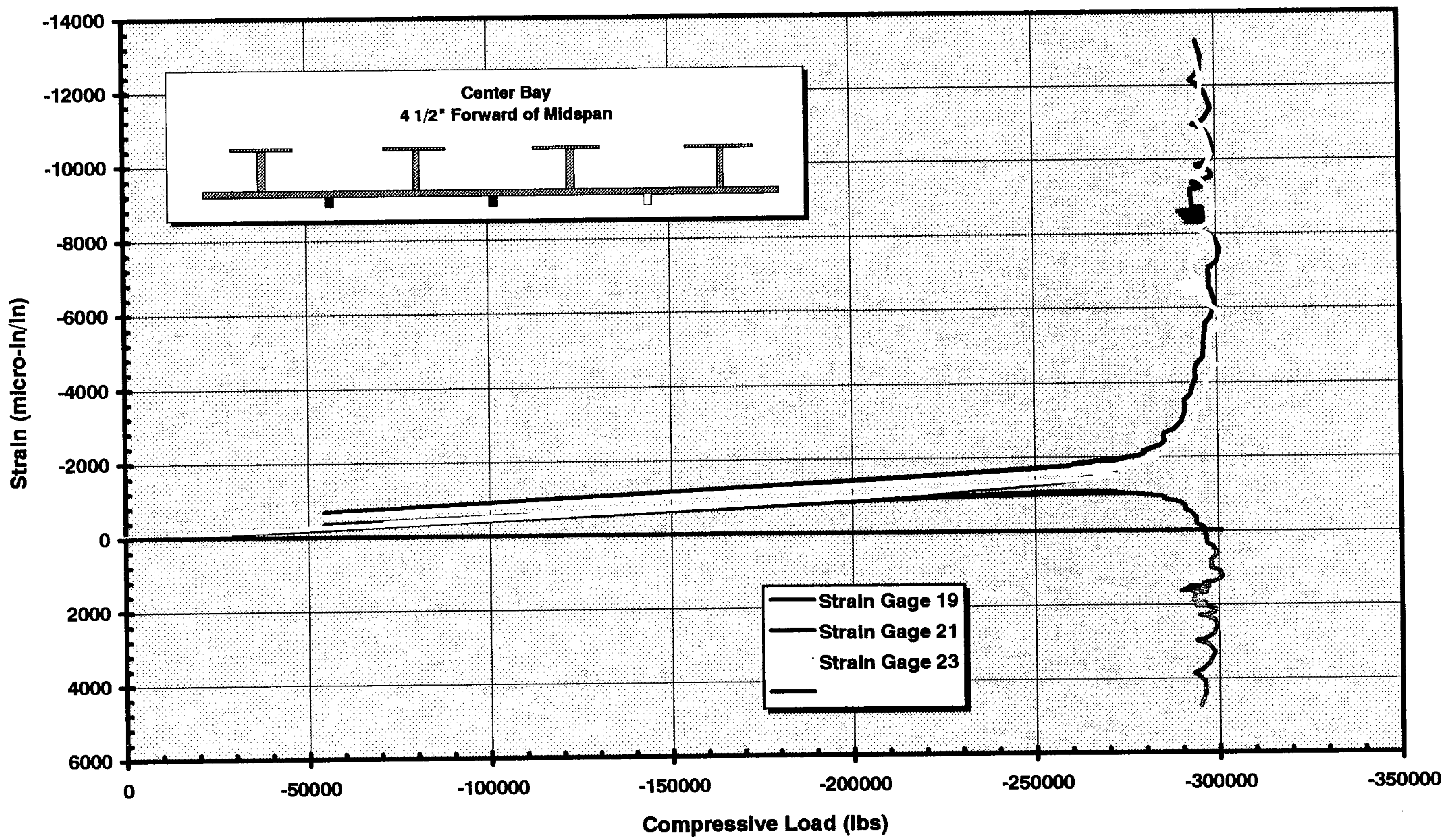

Strain vs. Applied Load
Forward Bay
4 1/2 " Aft of Midspan
Strain (micro-in/in)
-1200
-1000
-800
-600
-400
-200
0
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)
Strain Gage 9
Strain Gage 10

Strain vs. Applied Load

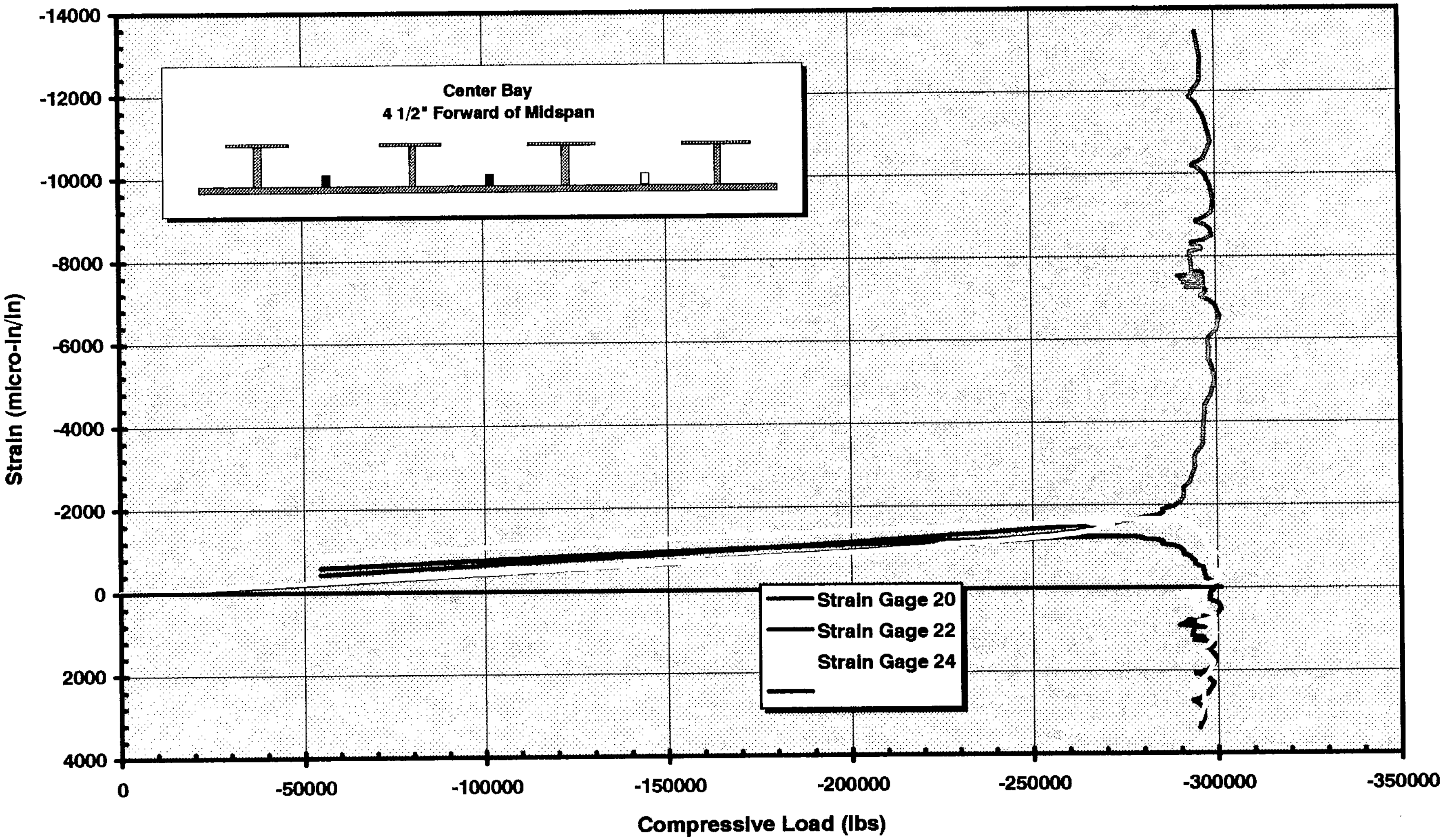



Strain vs. Applied Load
Center Bay
1" Aft of Forward End
Strain (micro-in/in)
-2500
-2000
-1500
-1000
-500
0
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)
Strain Gage 12
Strain Gage 14
Strain Gage 16
Strain Gage 18

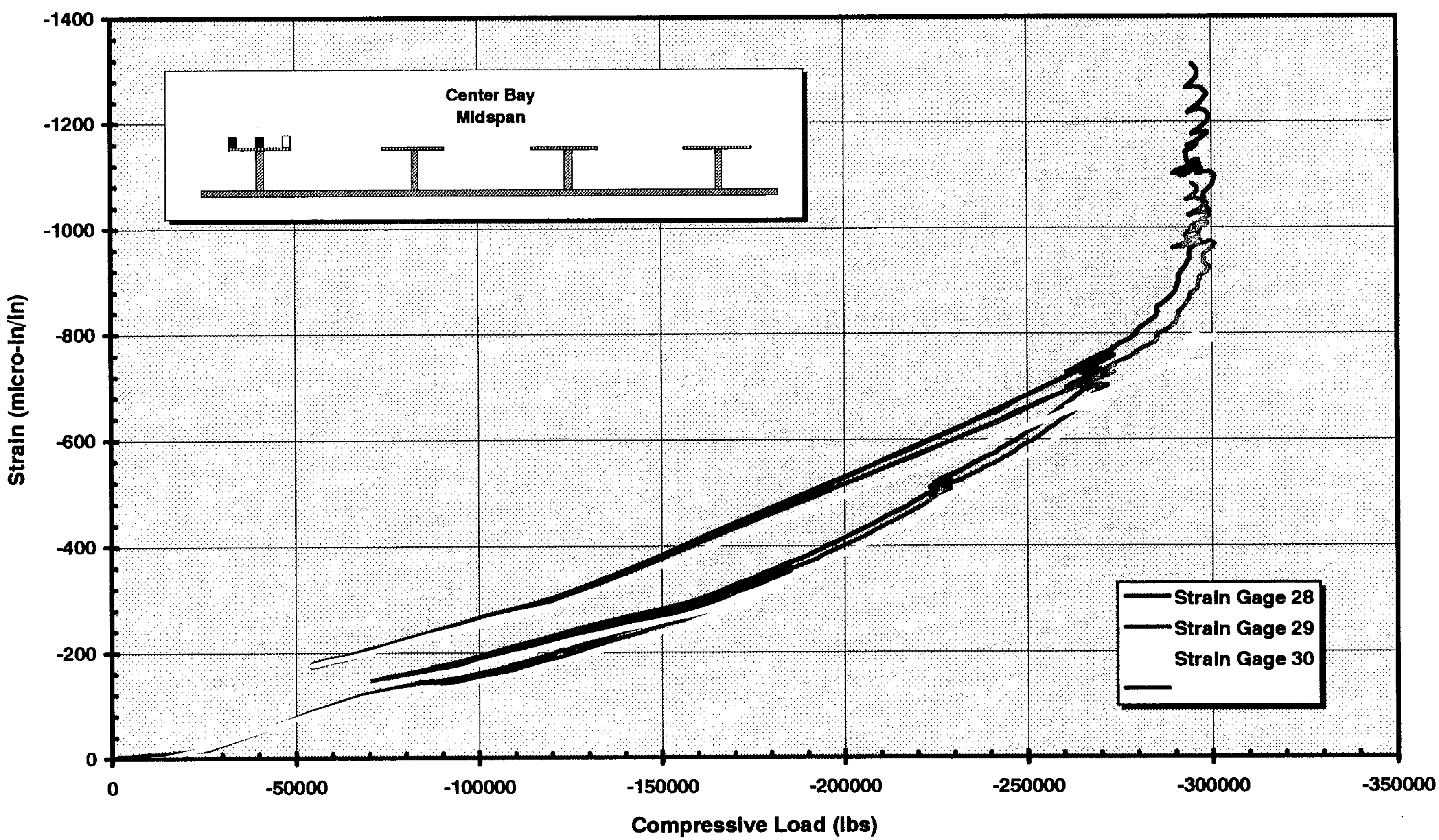
Strain vs. Applied Load



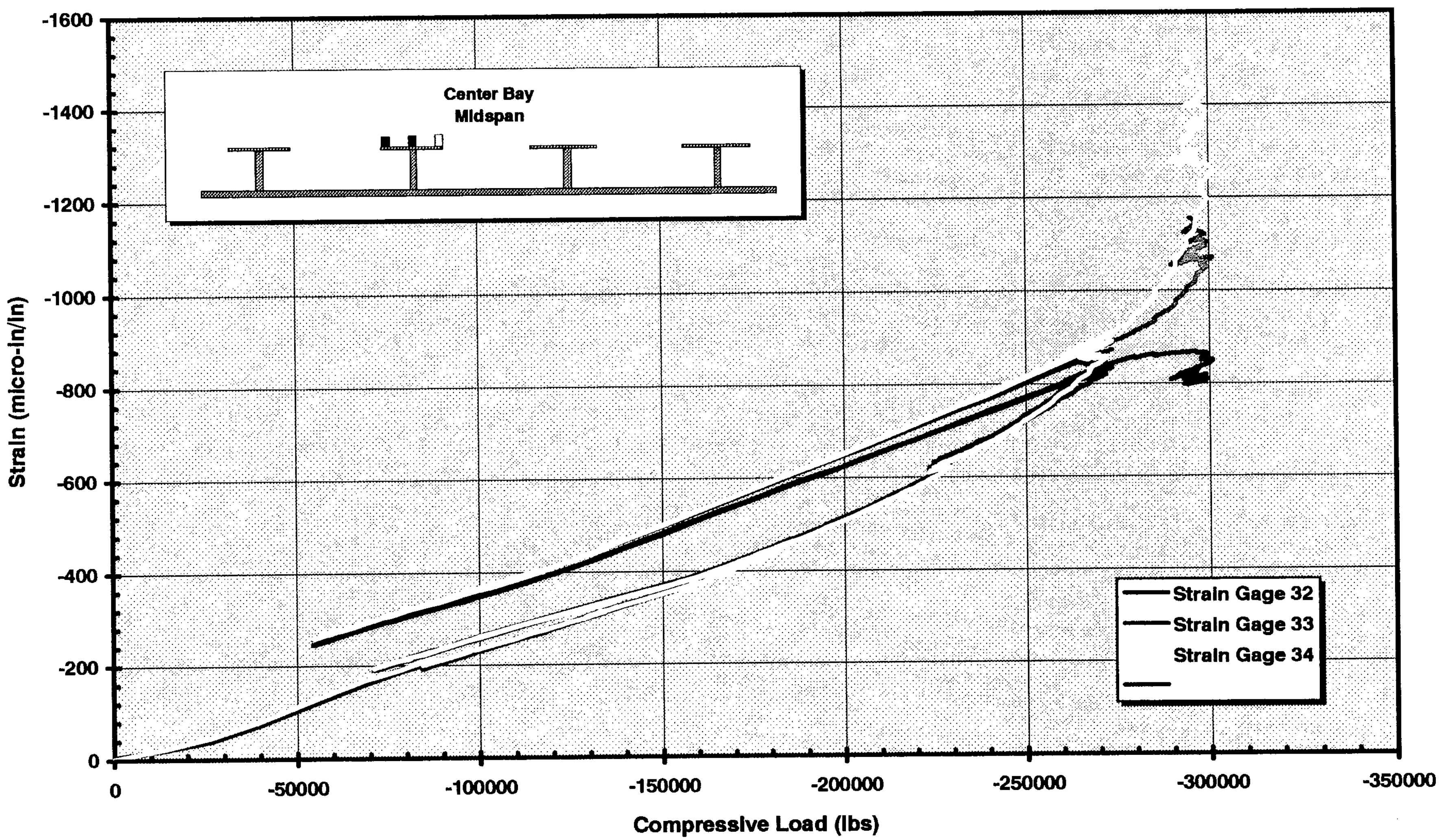
Strain vs. Applied Load



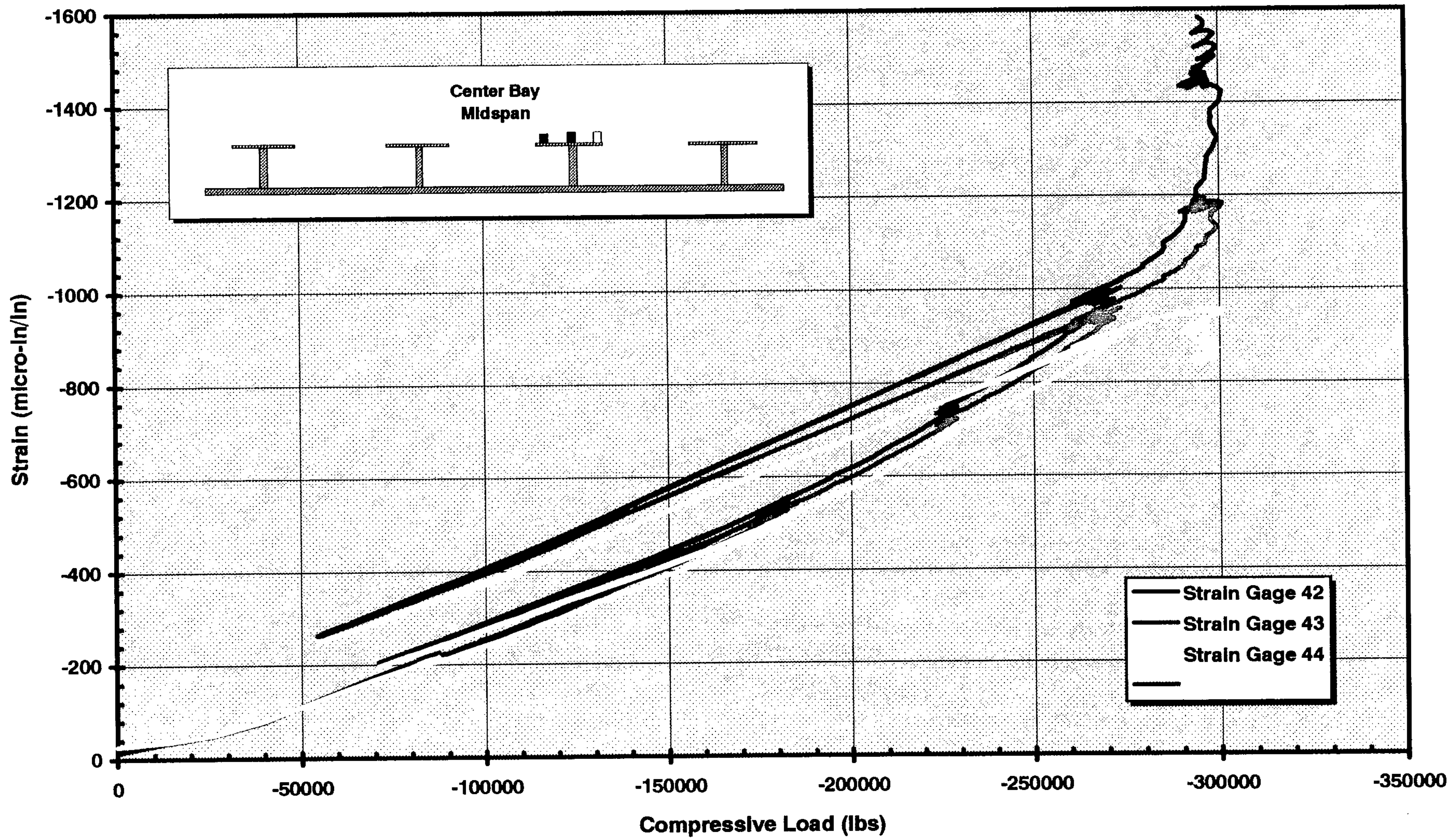
Strain vs. Applied Load



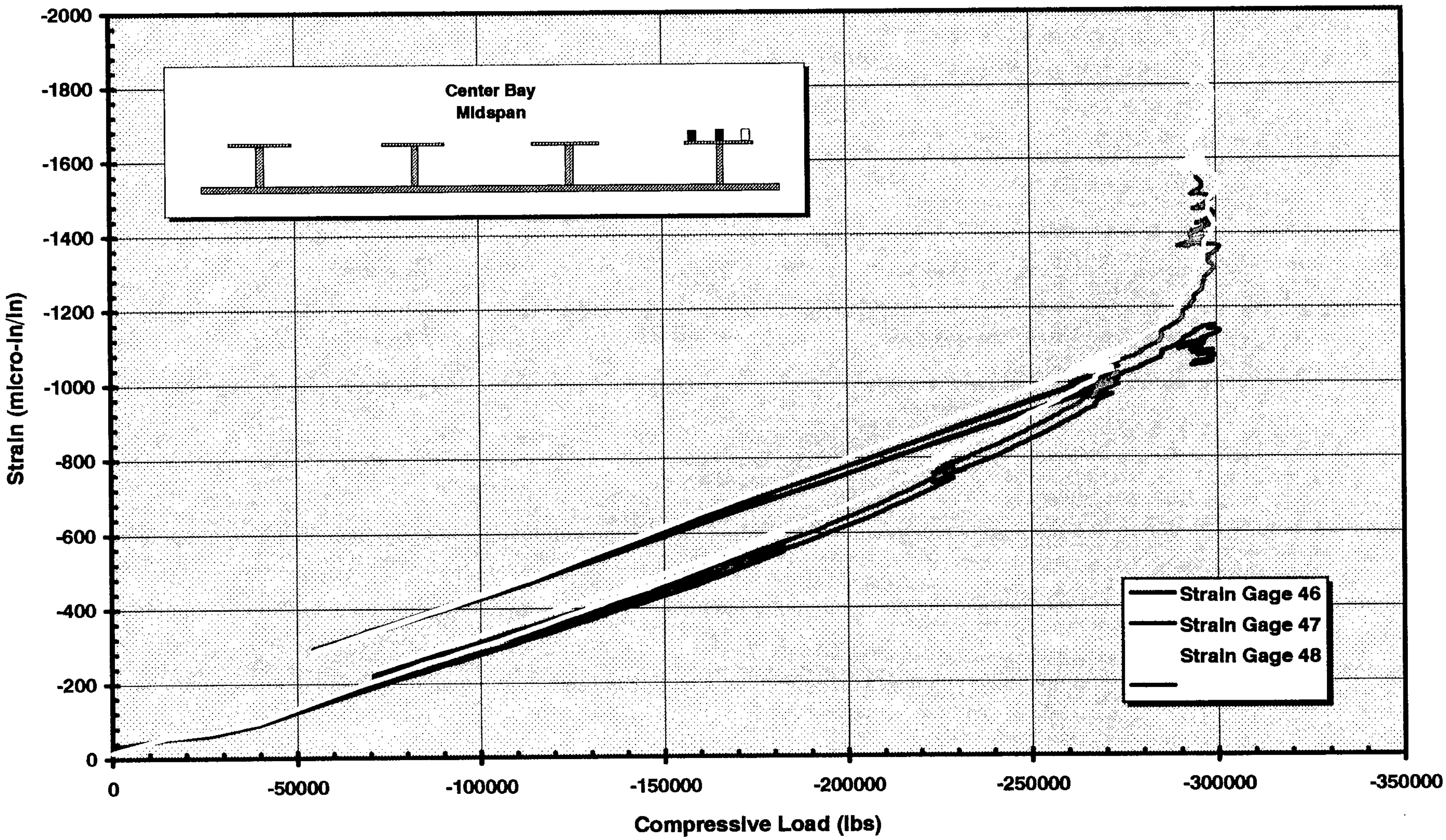
Strain vs. Applied Load



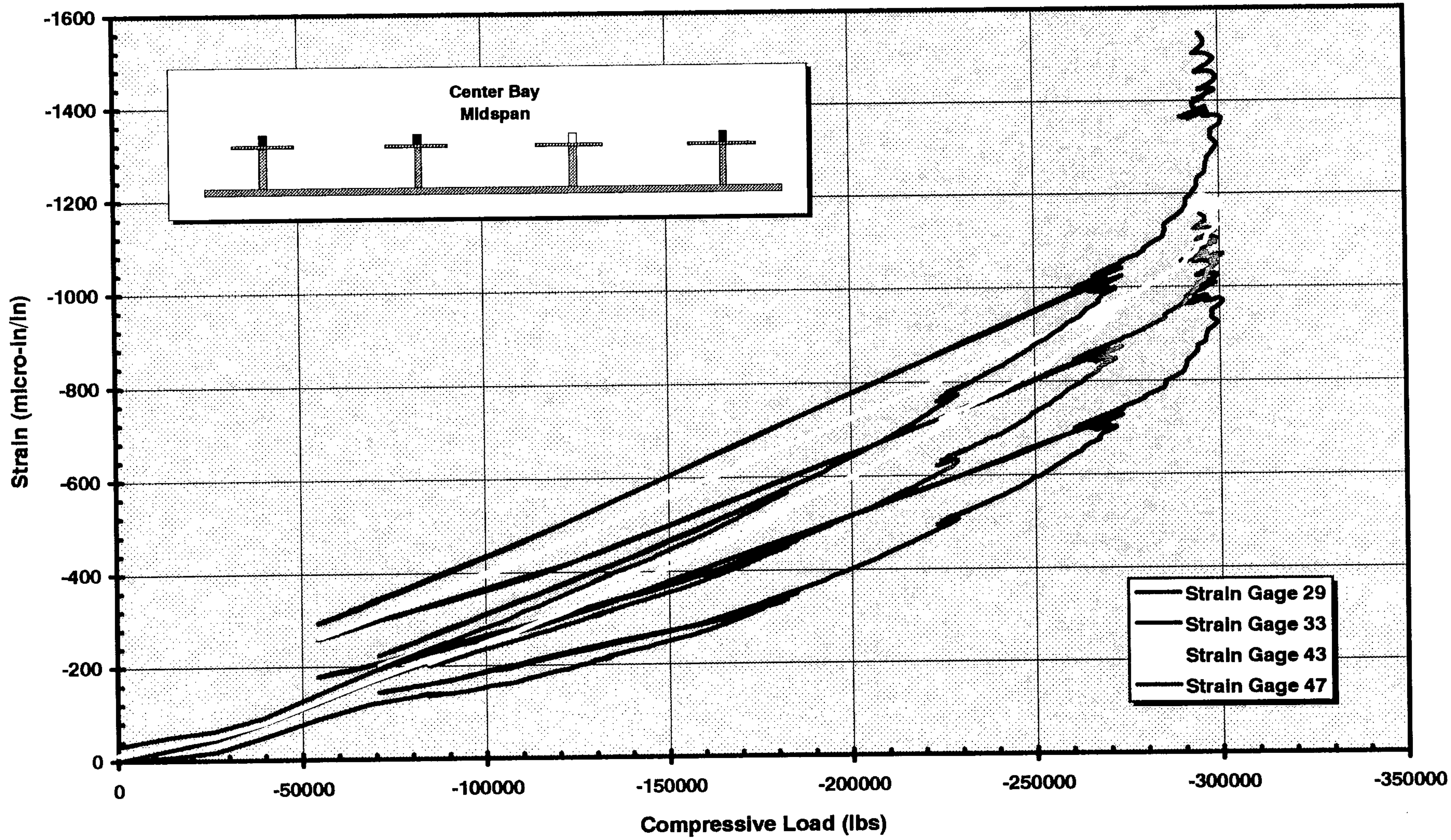
Strain vs. Applied Load



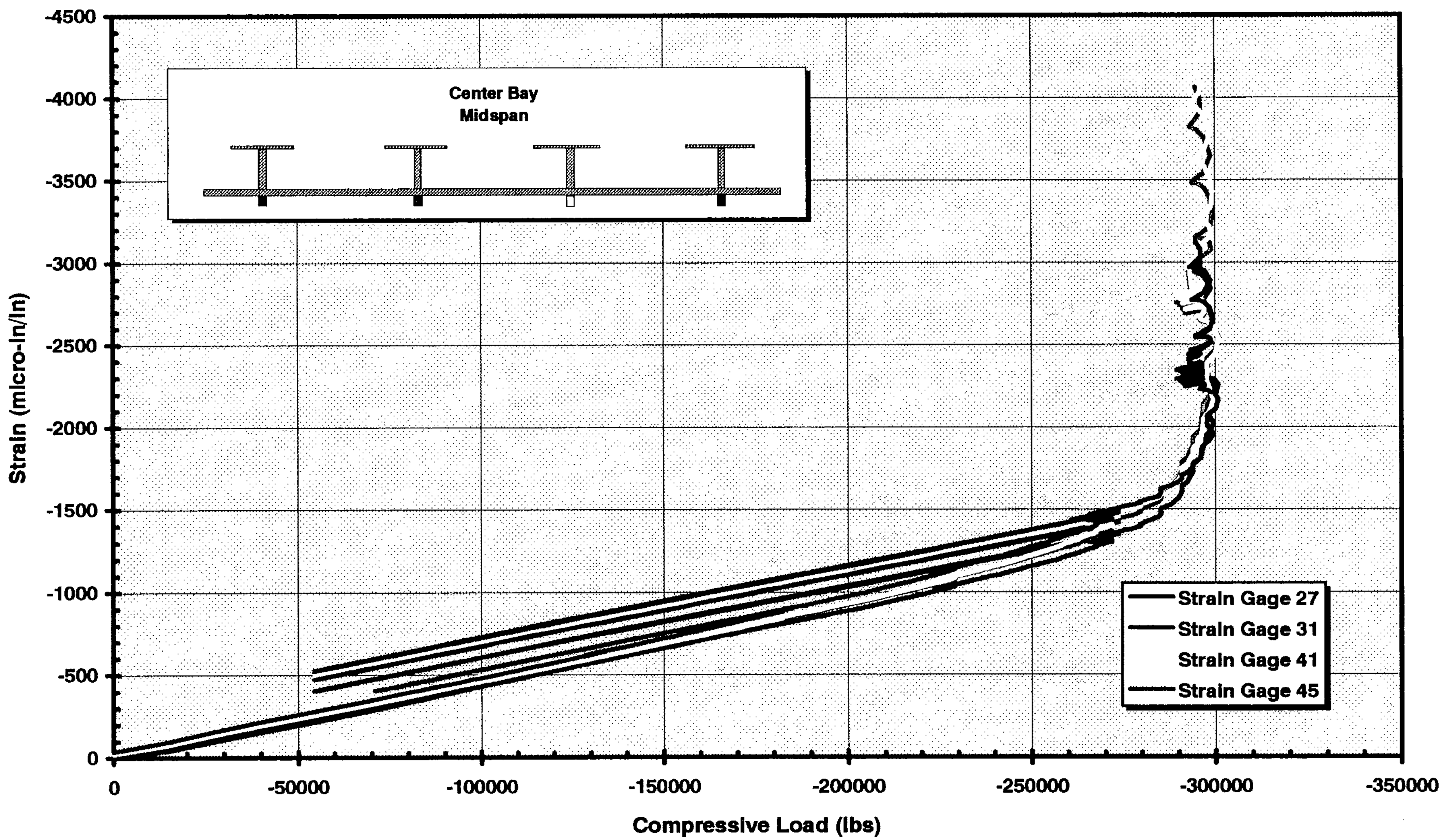
Strain vs. Applied Load



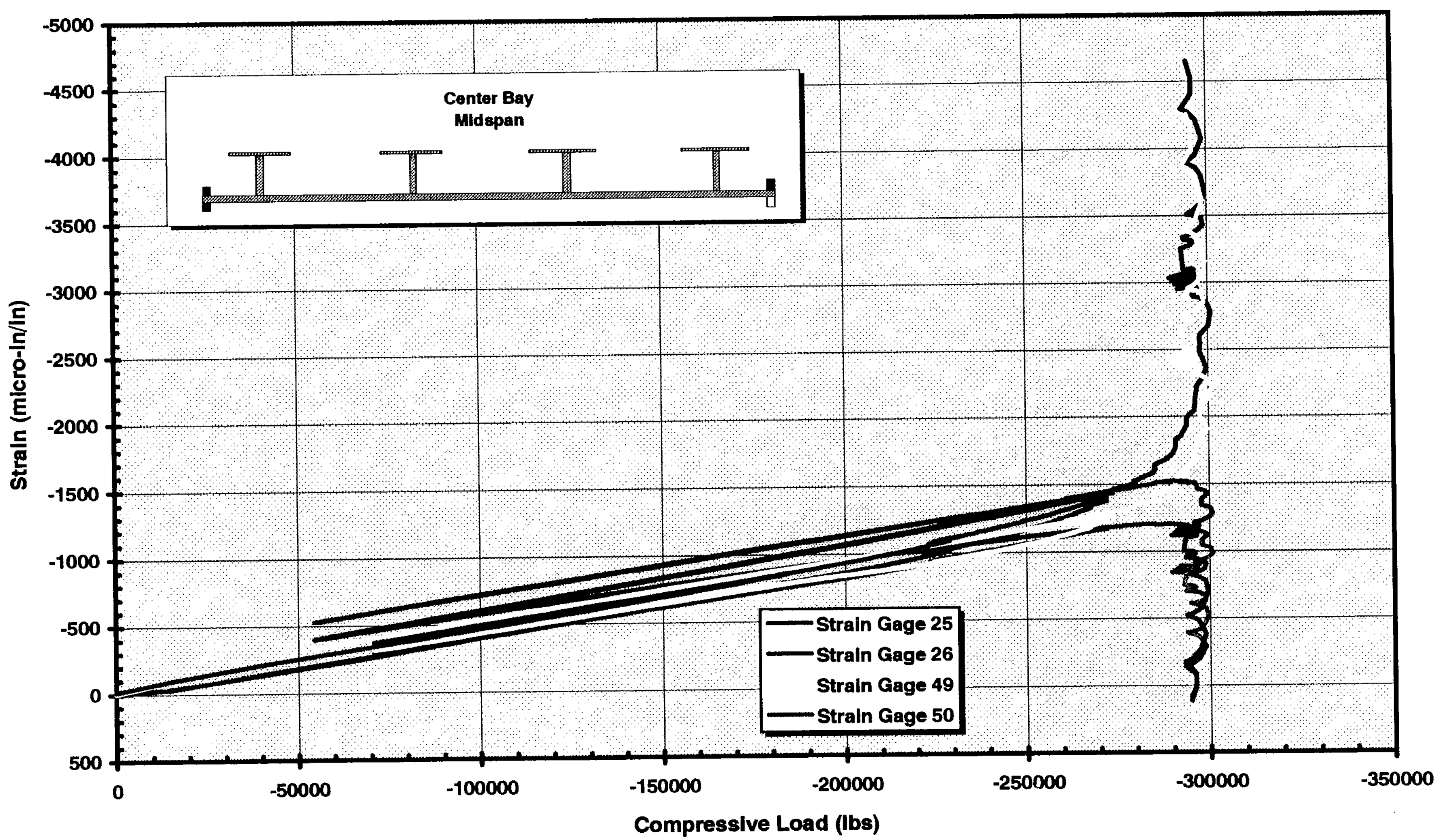
Strain vs. Applied Load



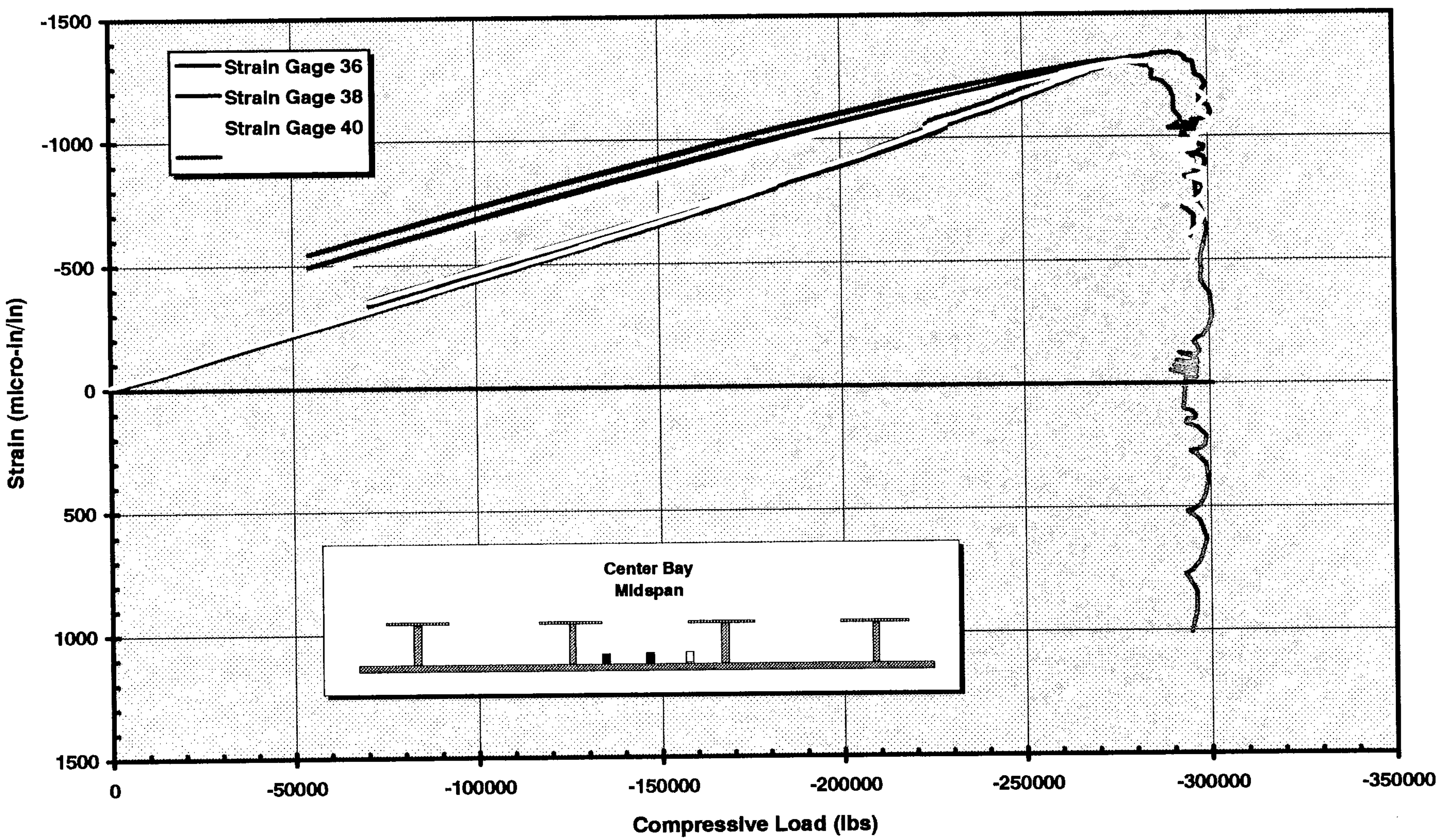
Strain vs. Applied Load



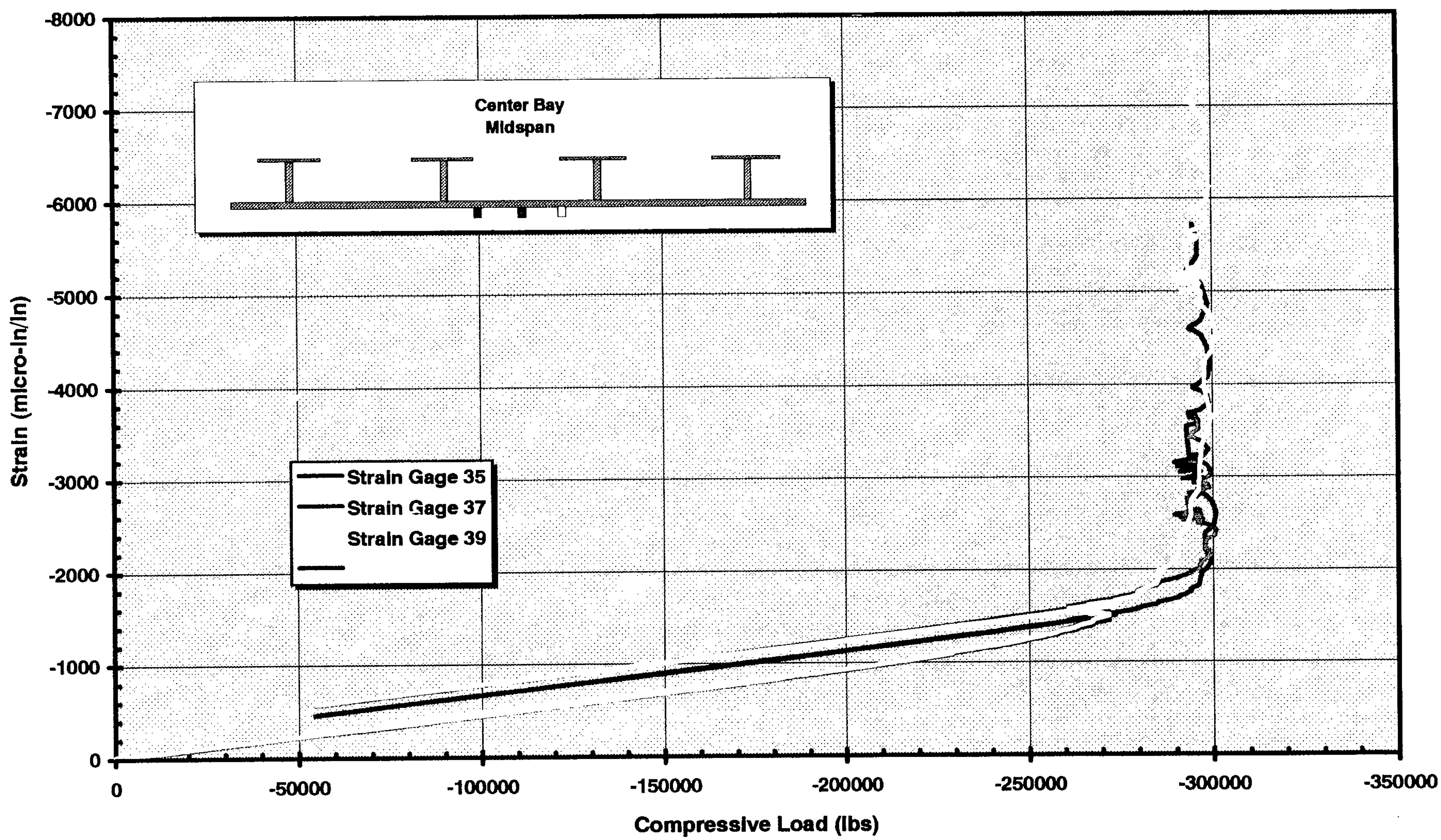
Strain vs. Applied Load



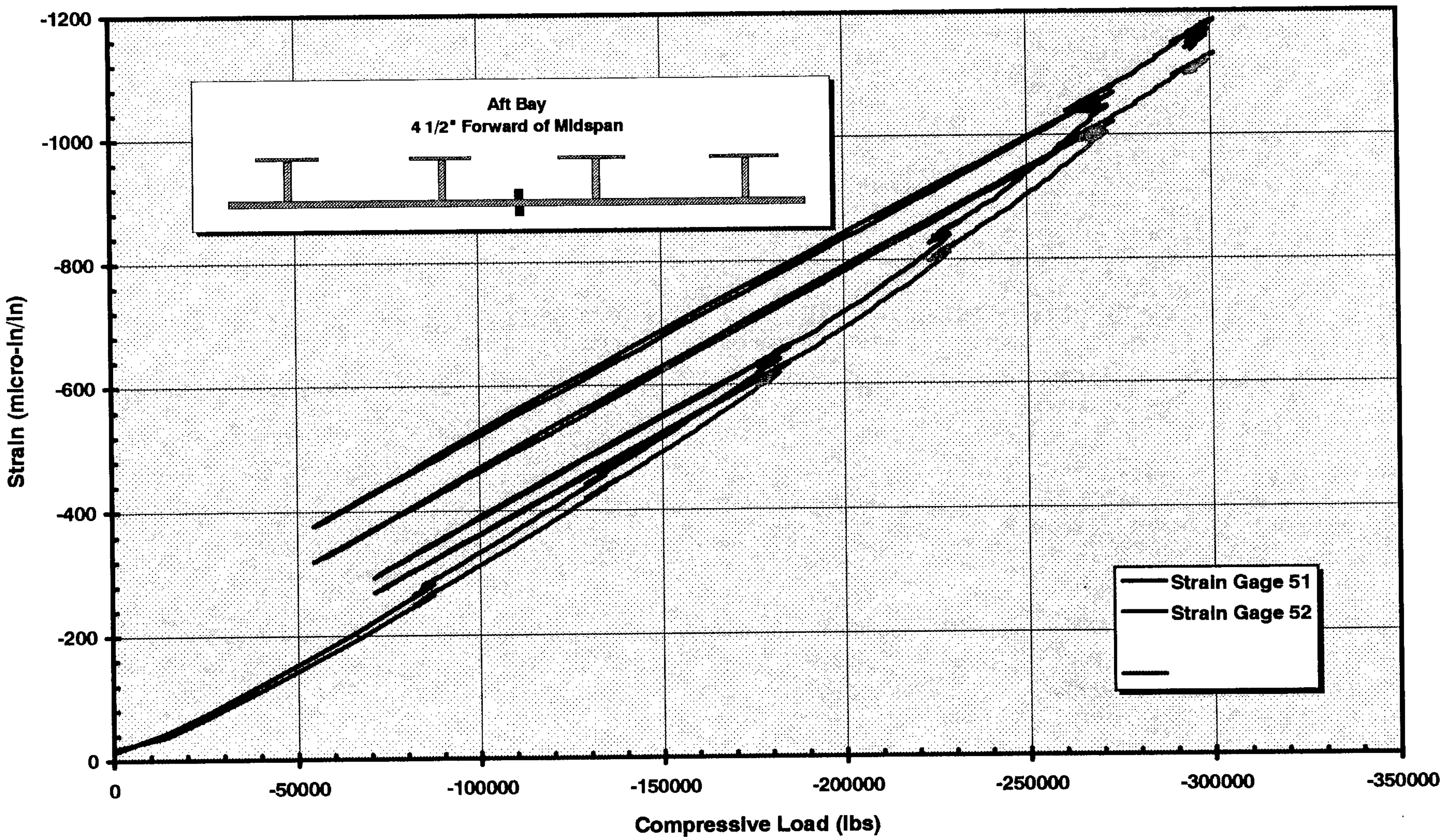
Strain vs. Applied Load

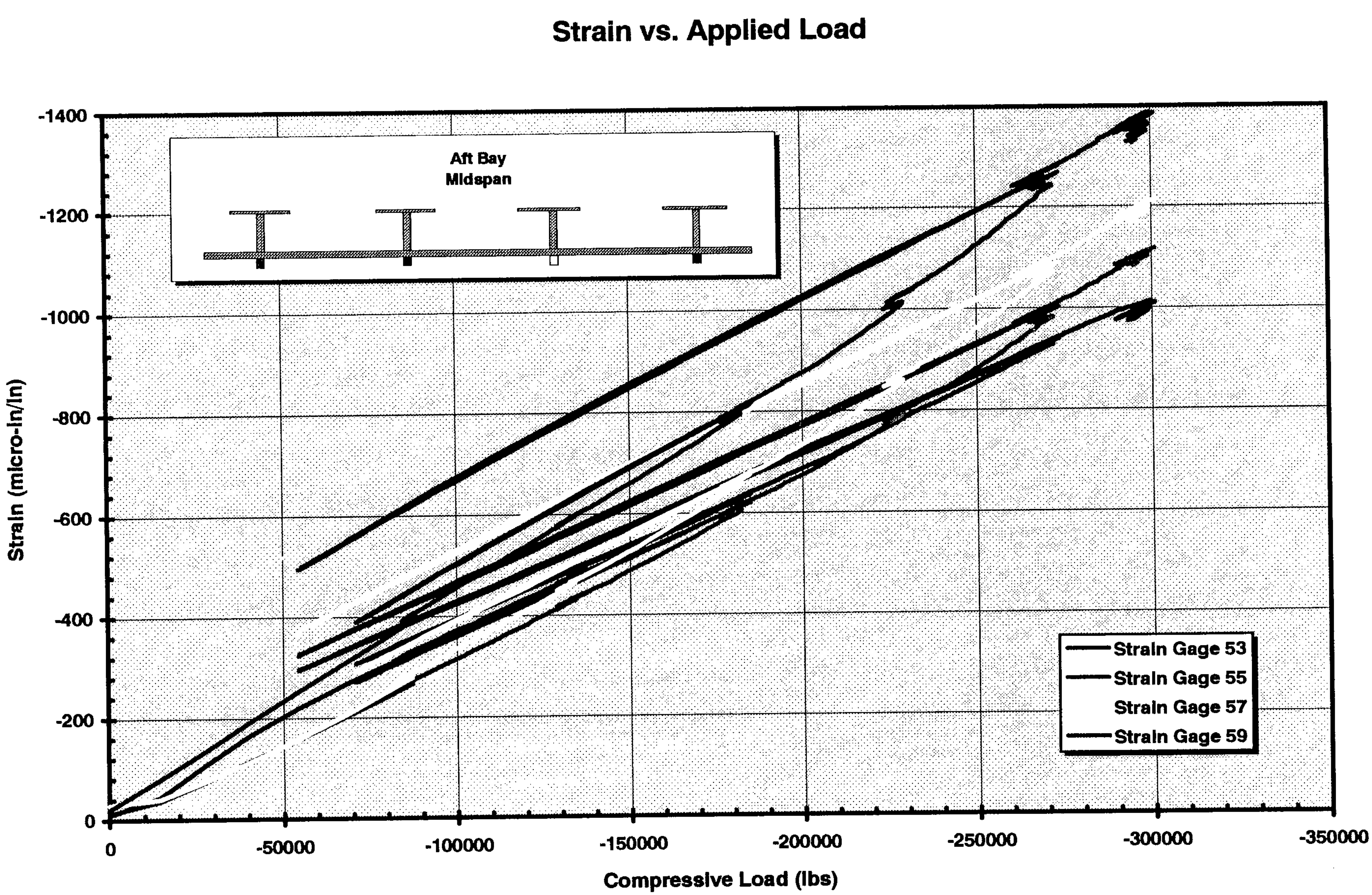


Strain vs. Applied Load

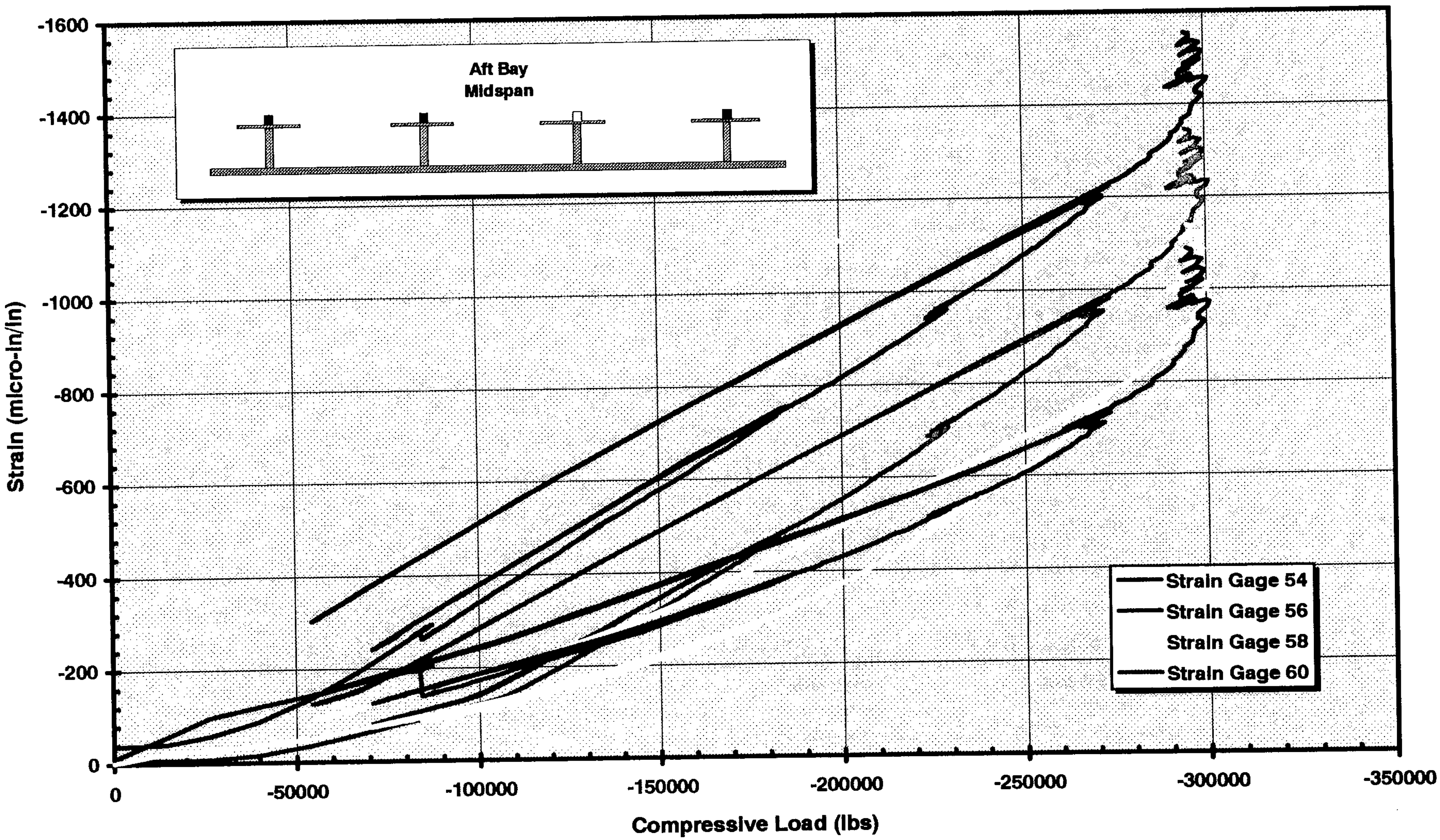


Strain vs. Applied Load



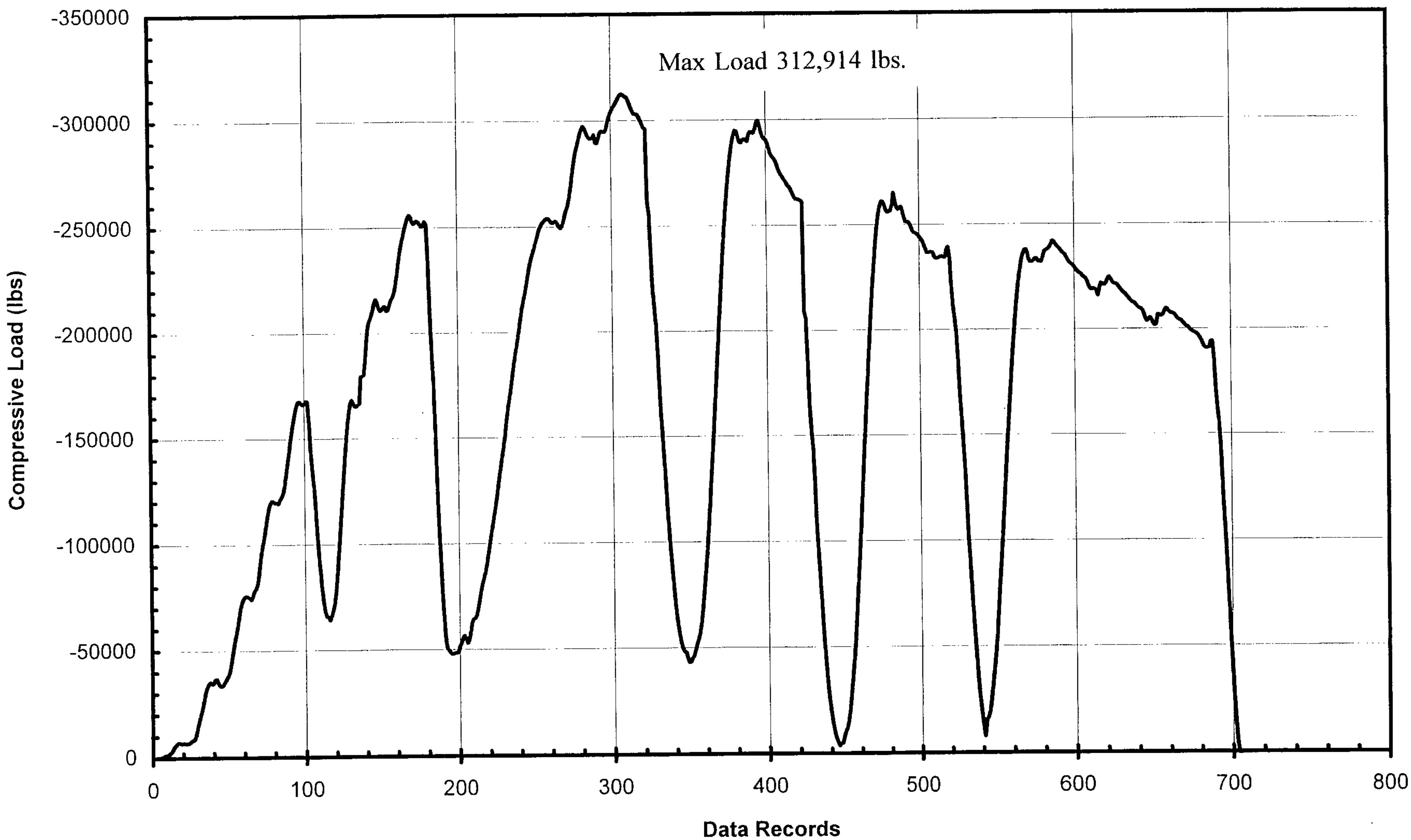

Strain vs. Applied Load
Aft Bay
Midspan
Strain Gage 53
Strain Gage 55
Strain Gage 57
Strain Gage 59
-1400
-1200
-1000
-800
-600
-400
-200
0
Strain (micro-in/in)
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)

Strain vs. Applied Load

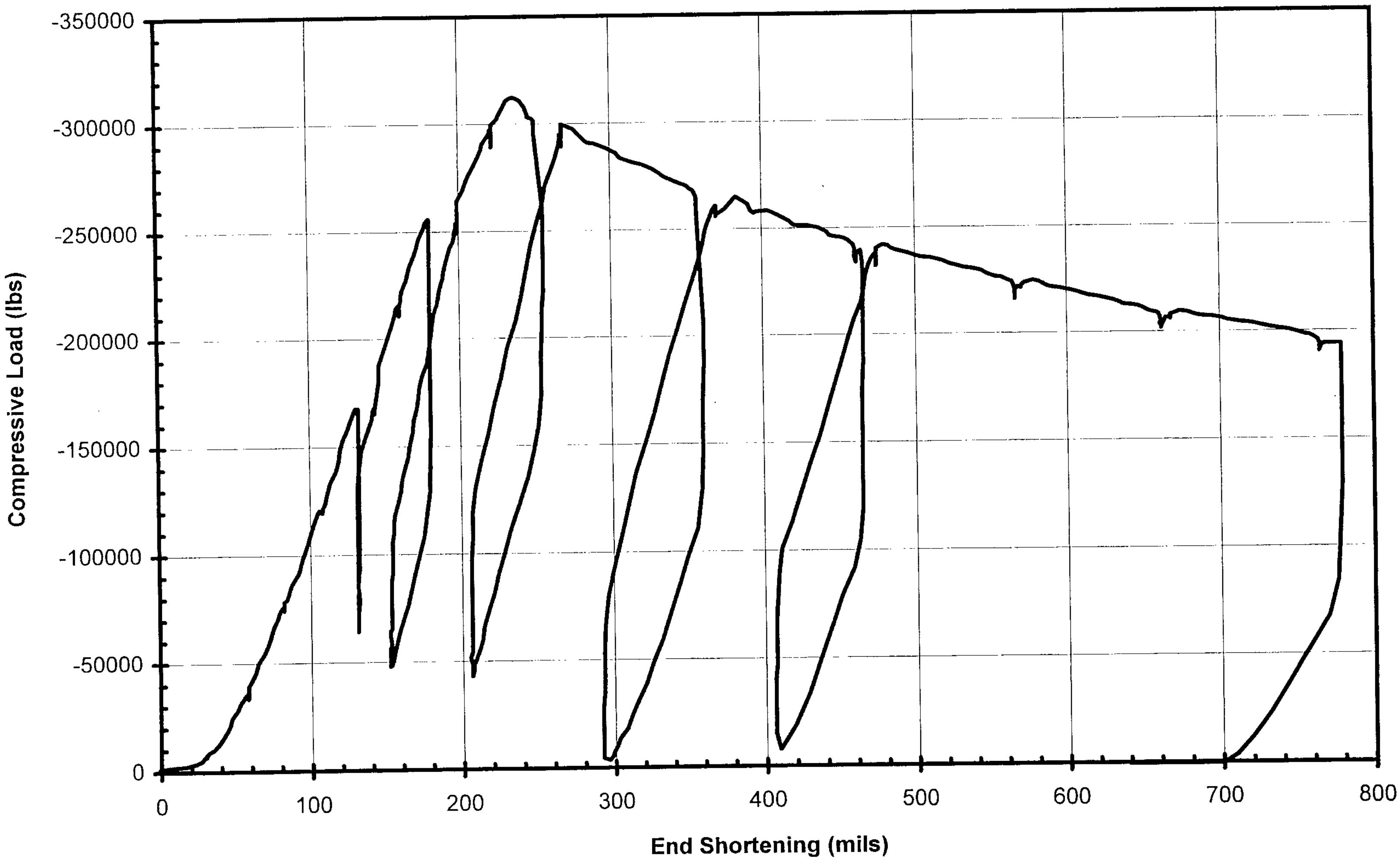


Specimen 1094 Axial Load

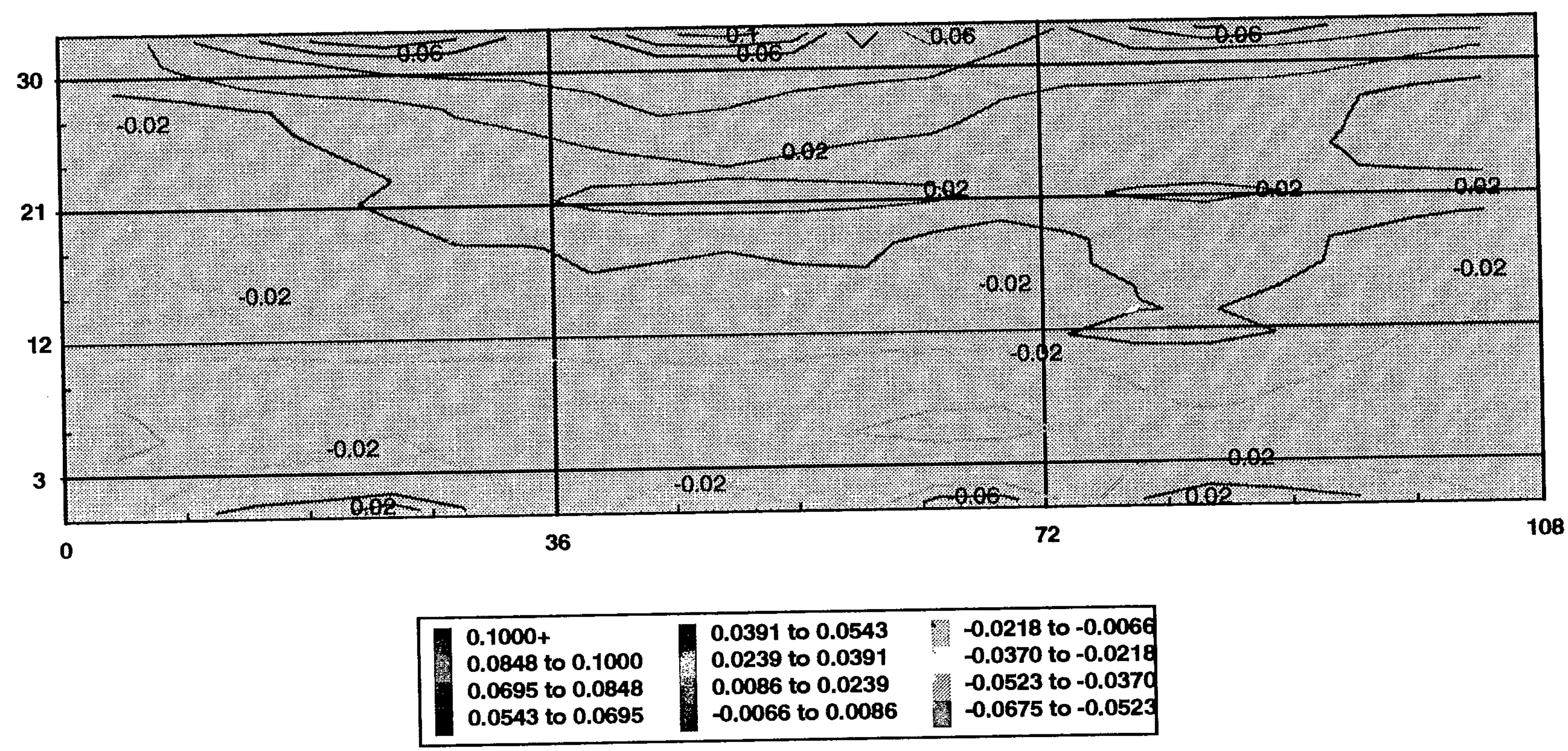
Load History



Load vs. End Shortening

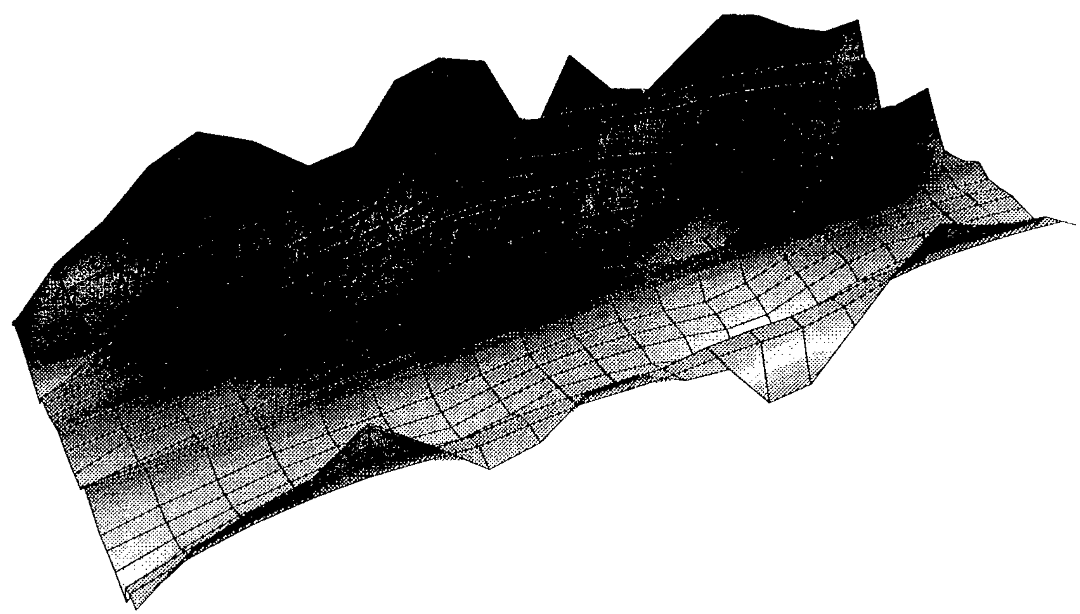


Pre-Test Survey

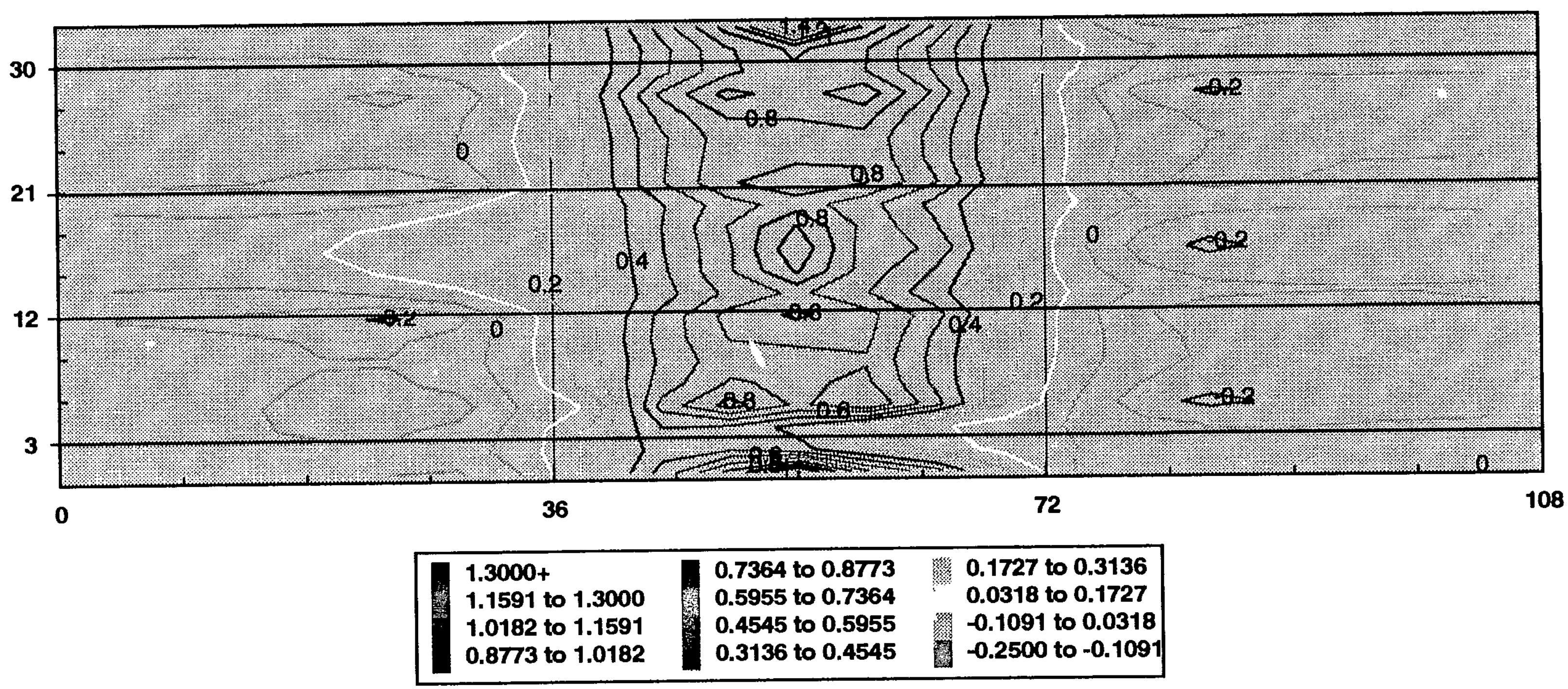


All measurements are in inches

Pre-Test Survey

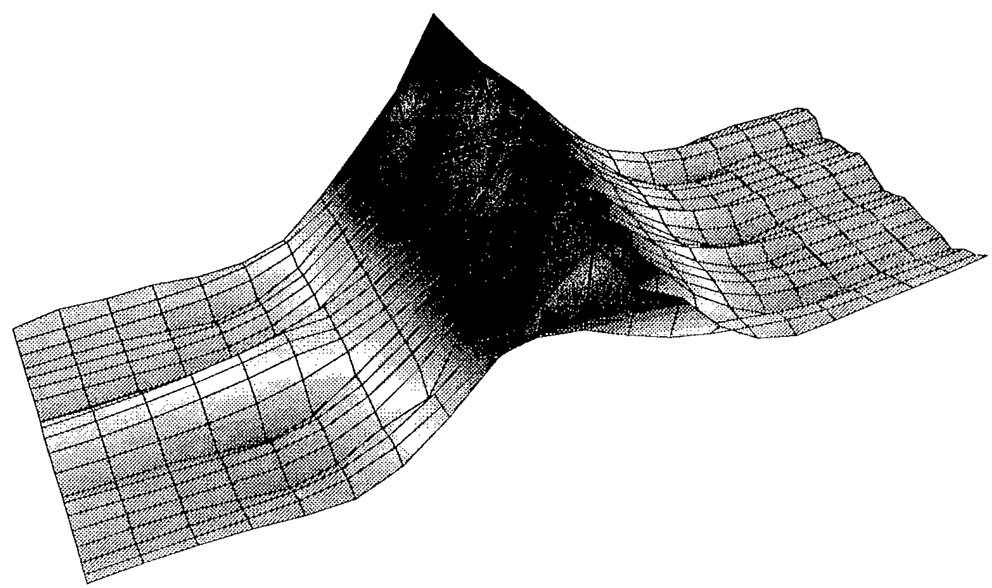


Post-Test Survey

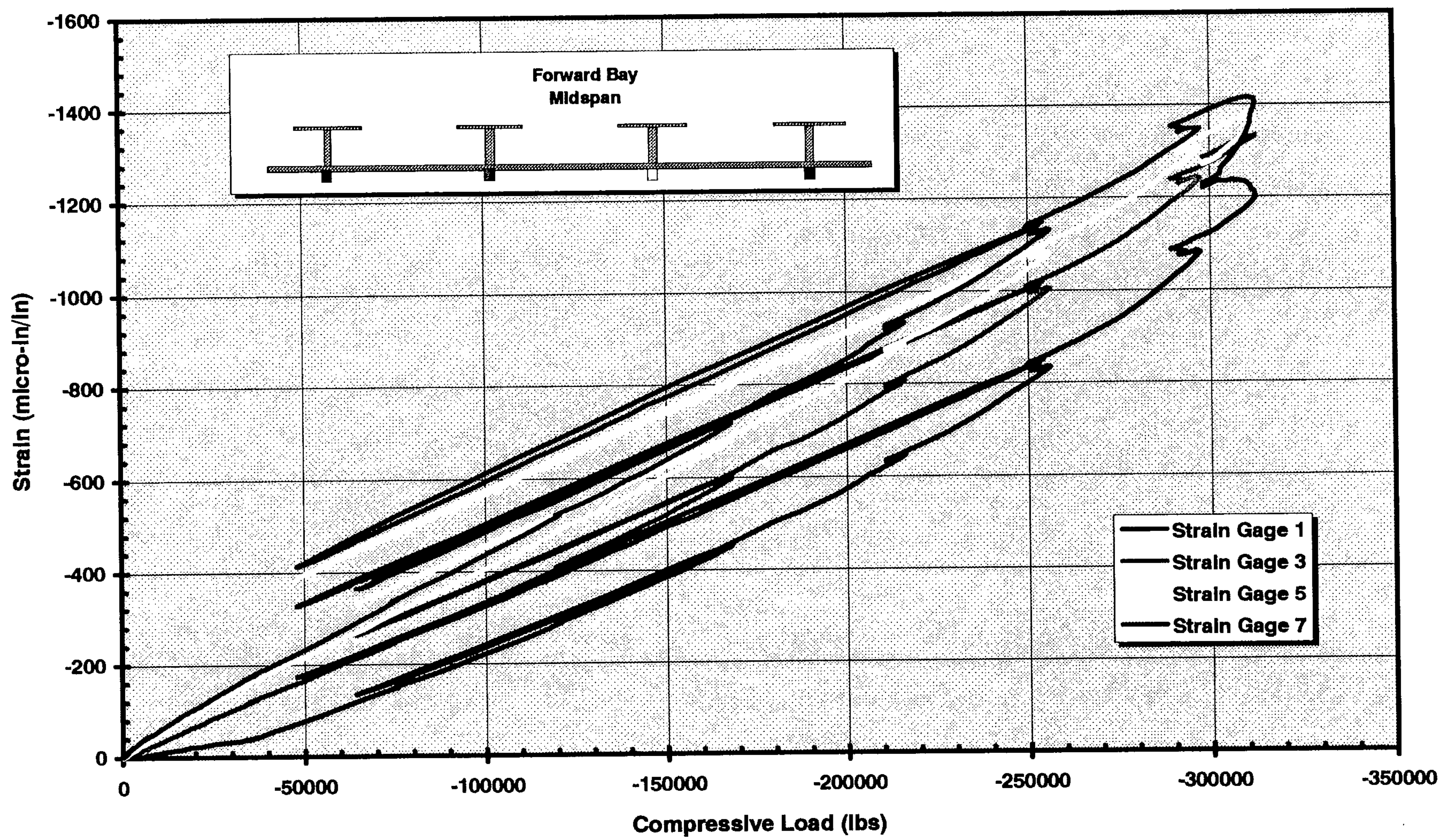


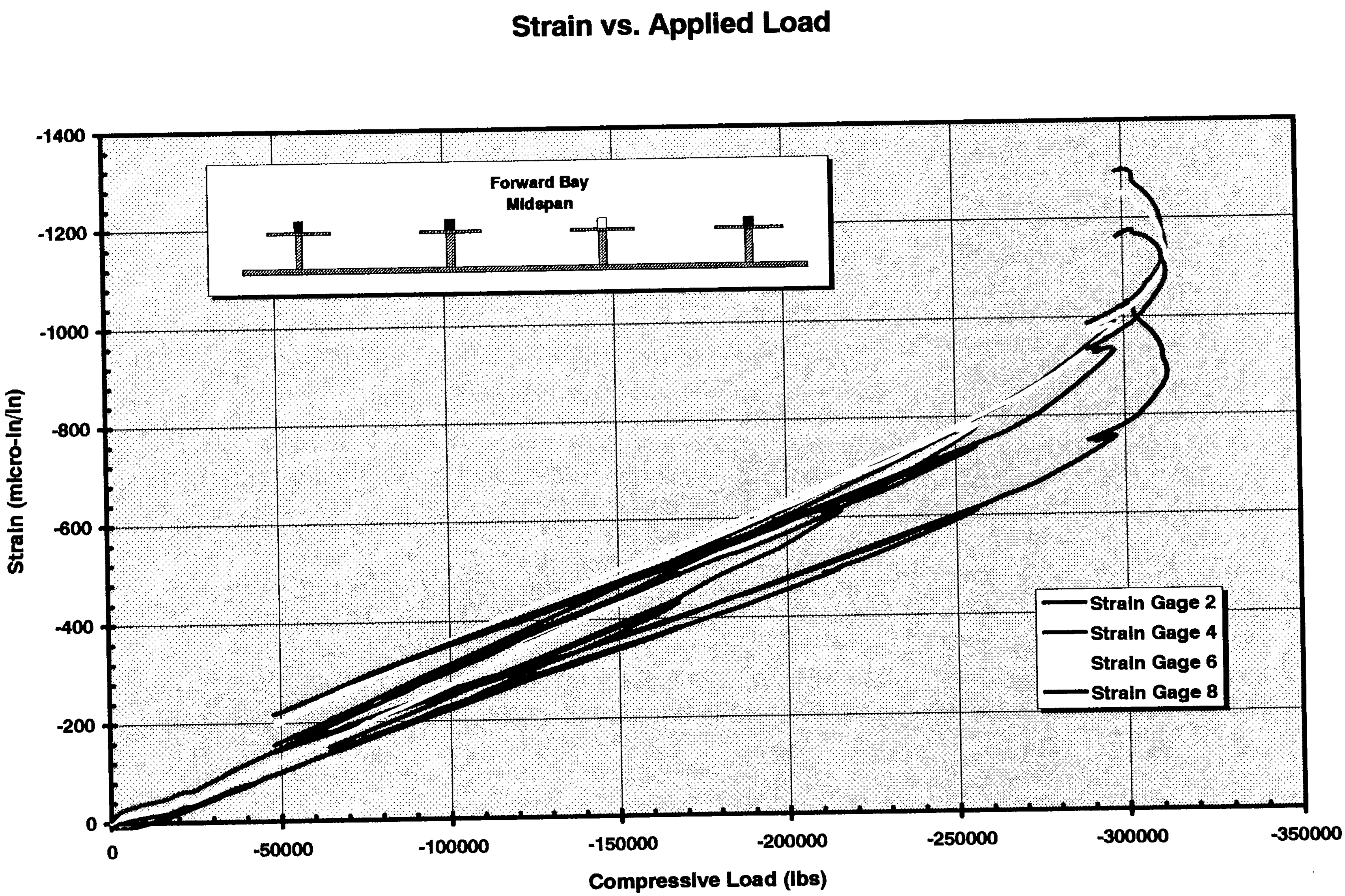
All measurements are in inches

Post-Test Survey

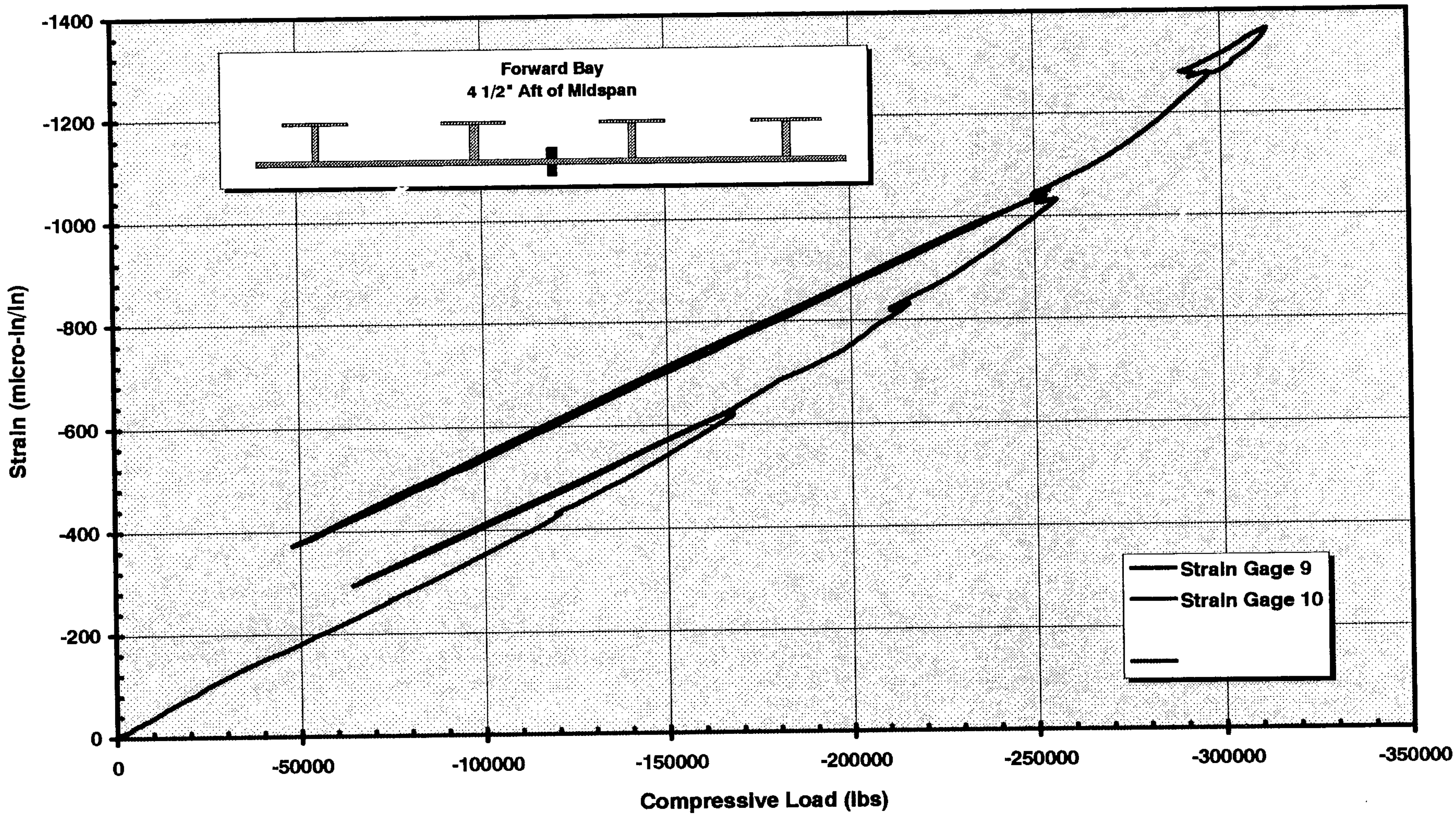


Strain vs. Applied Load

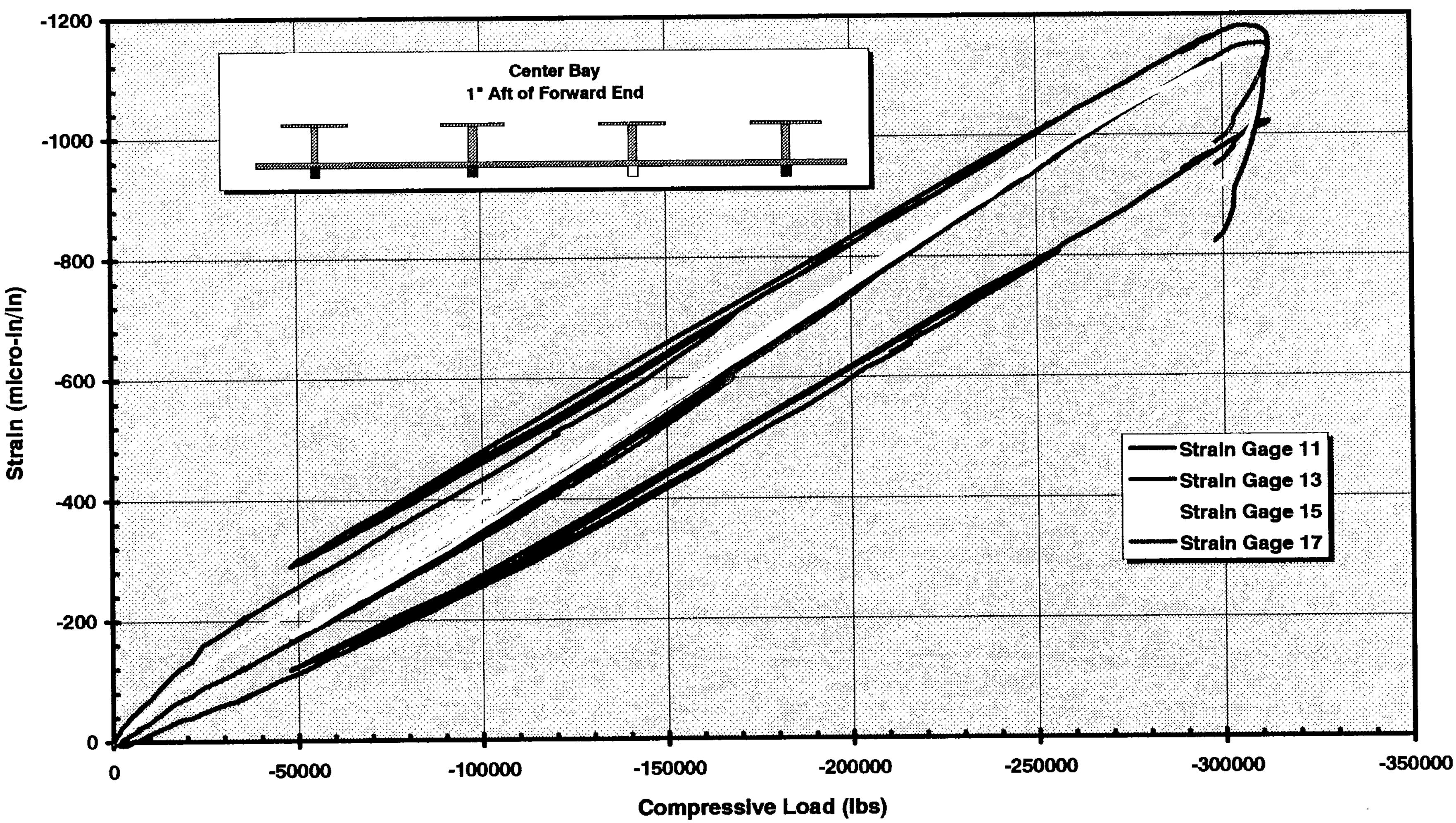



Strain vs. Applied Load
Forward Bay
Midspan
Strain (micro-in/in)
-1400
-1200
-1000
-800
-600
-400
-200
0
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)
Strain Gage 2
Strain Gage 4
Strain Gage 6
Strain Gage 8

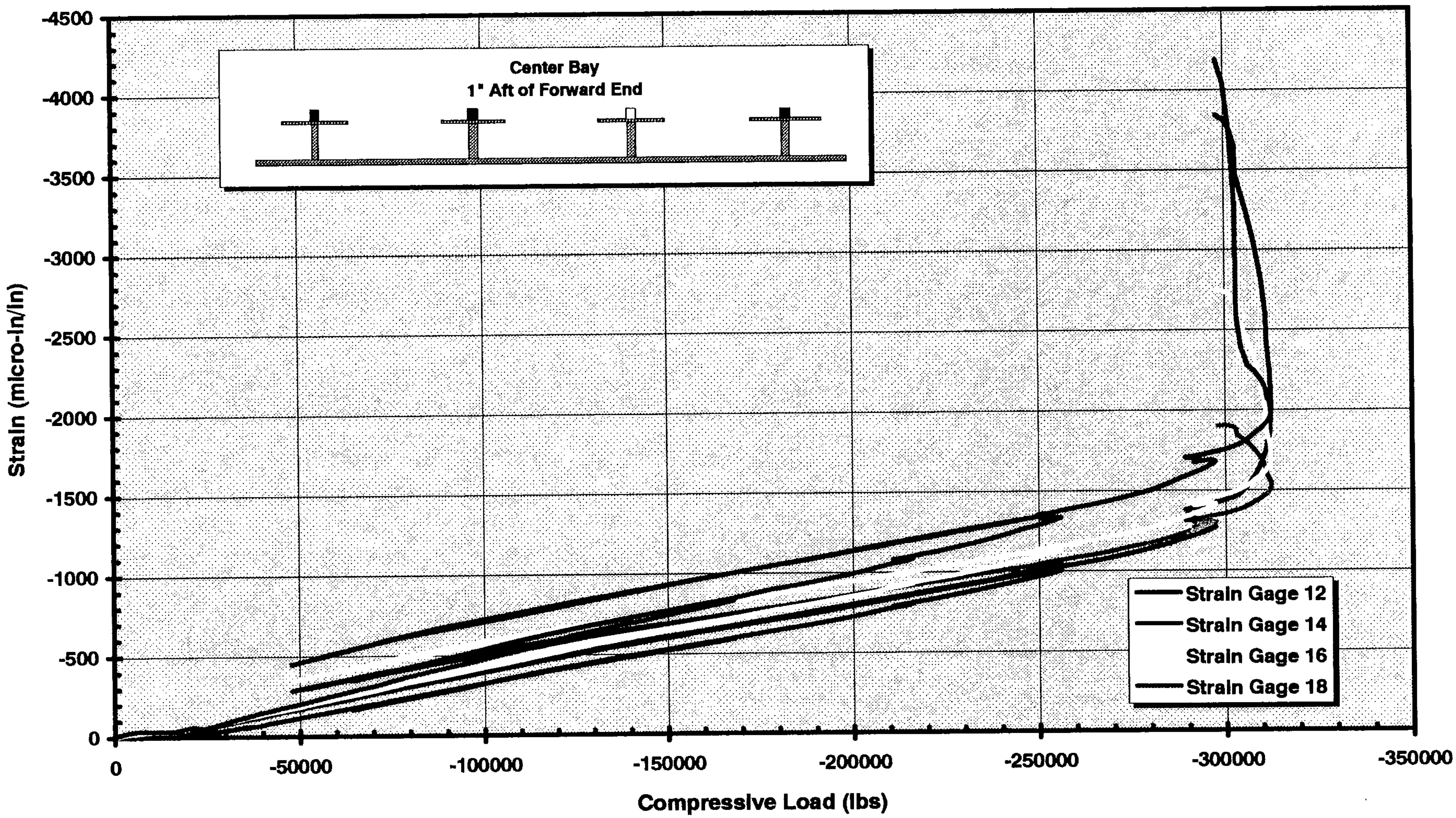
Strain vs. Applied Load



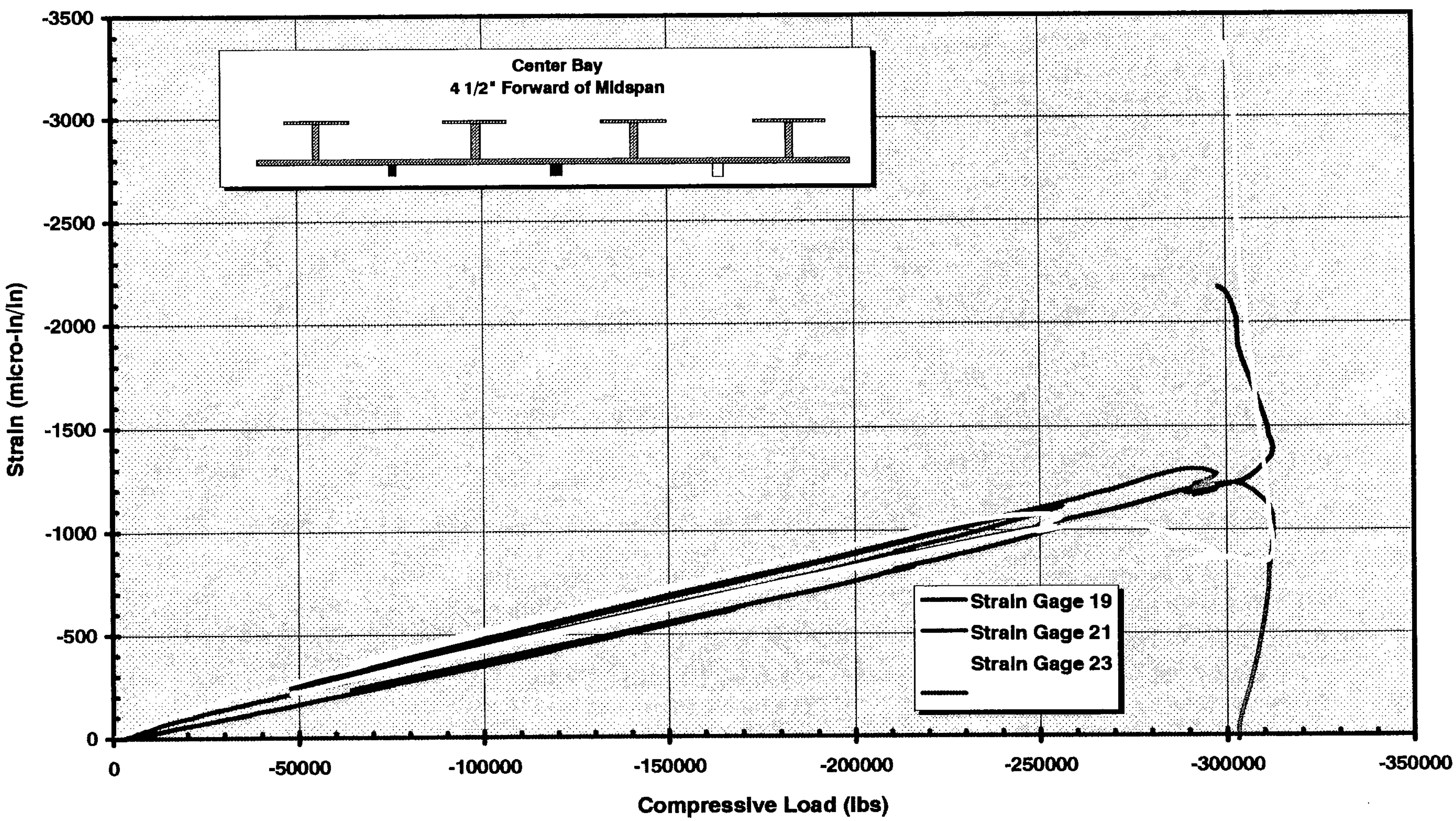
Strain vs. Applied Load



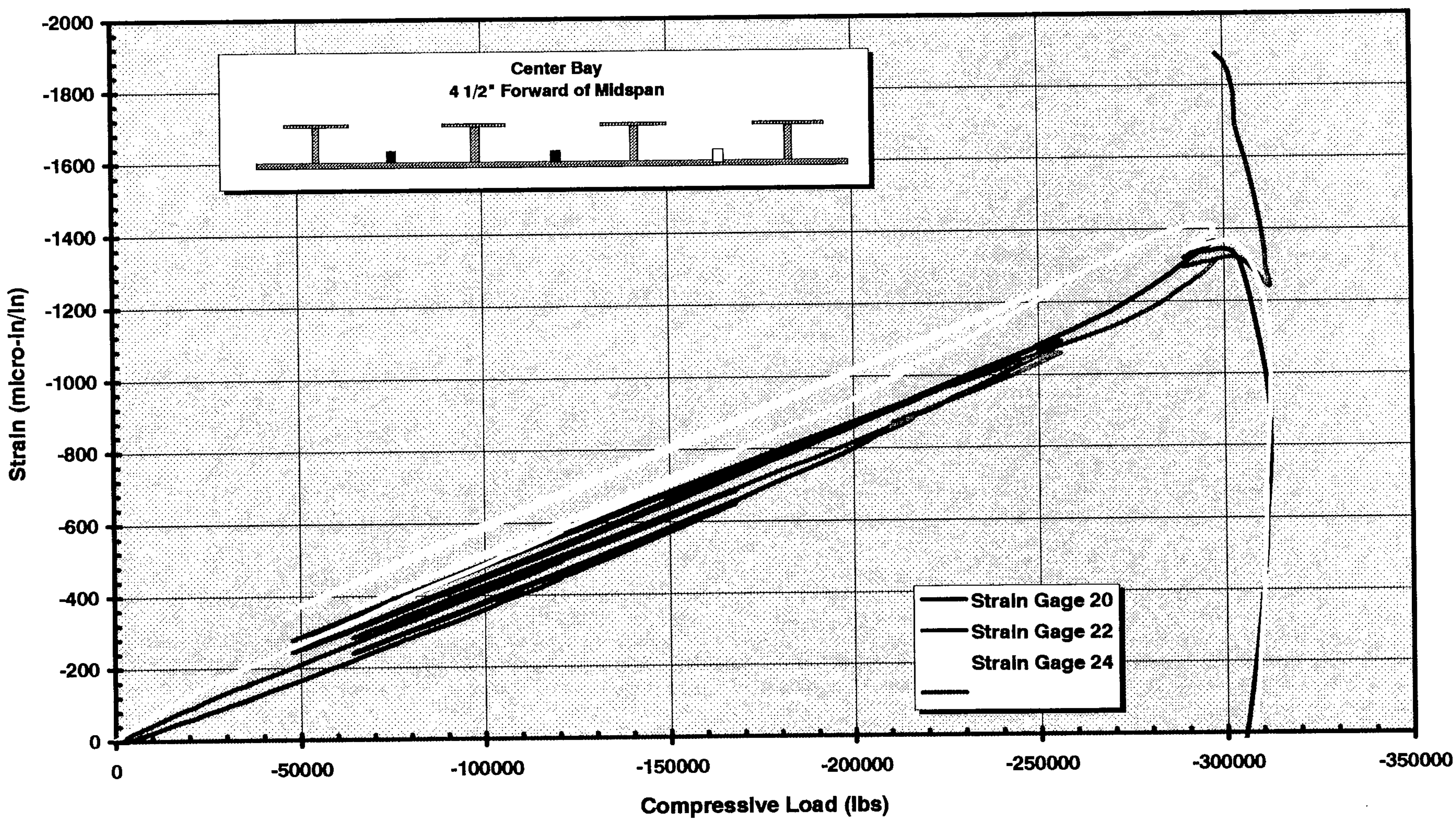
Strain vs. Applied Load



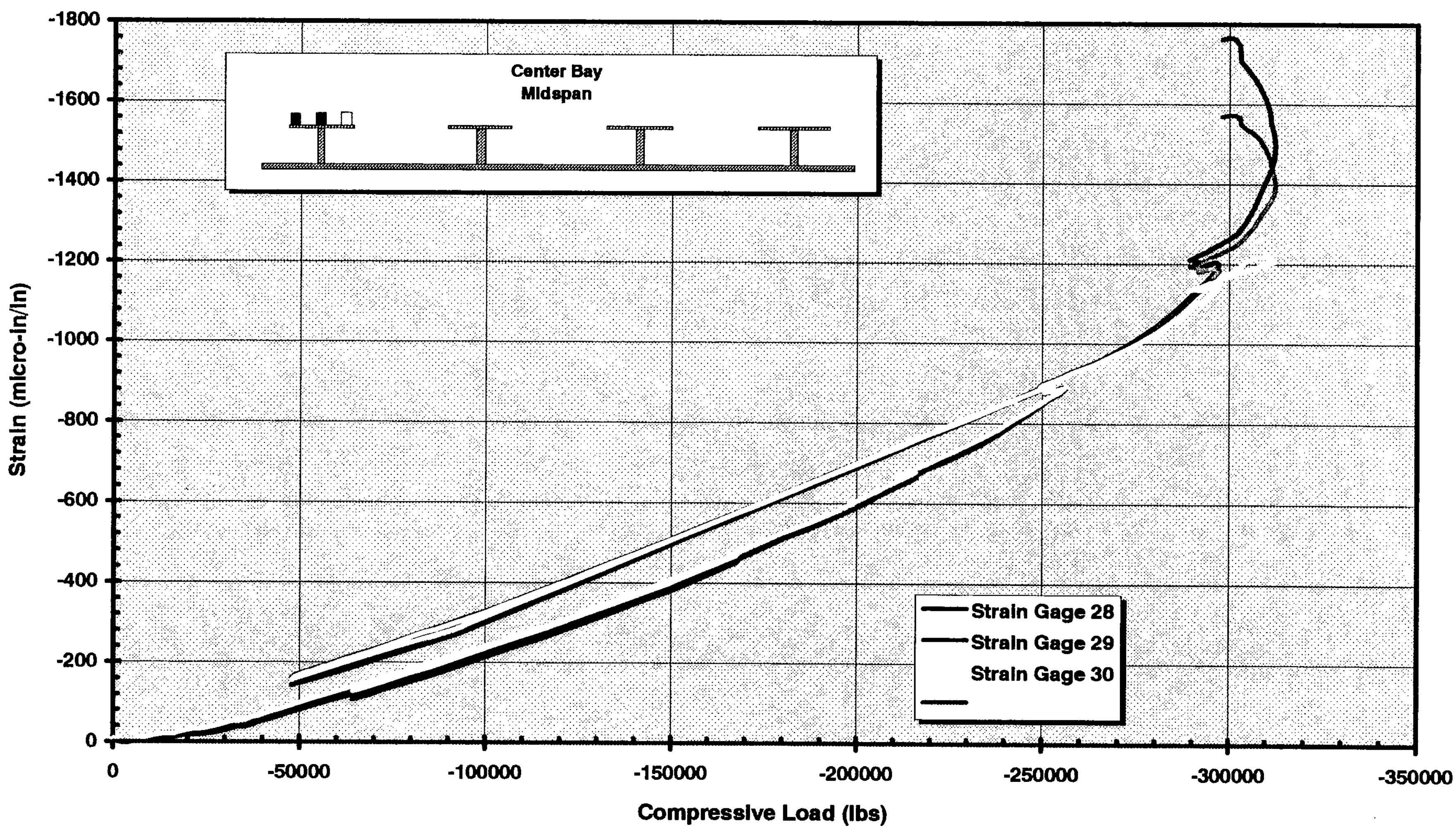
Strain vs. Applied Load



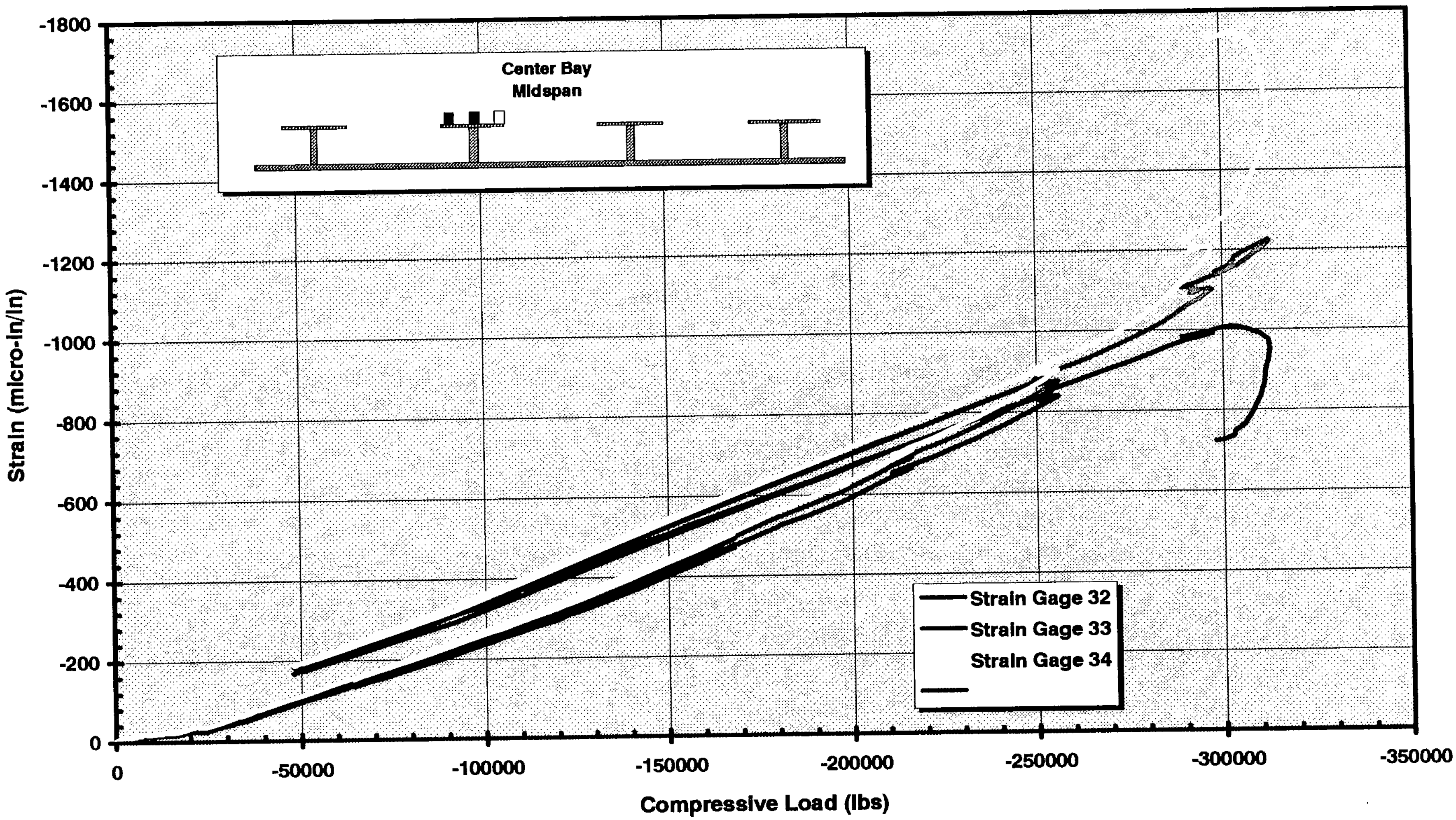
Strain vs. Applied Load



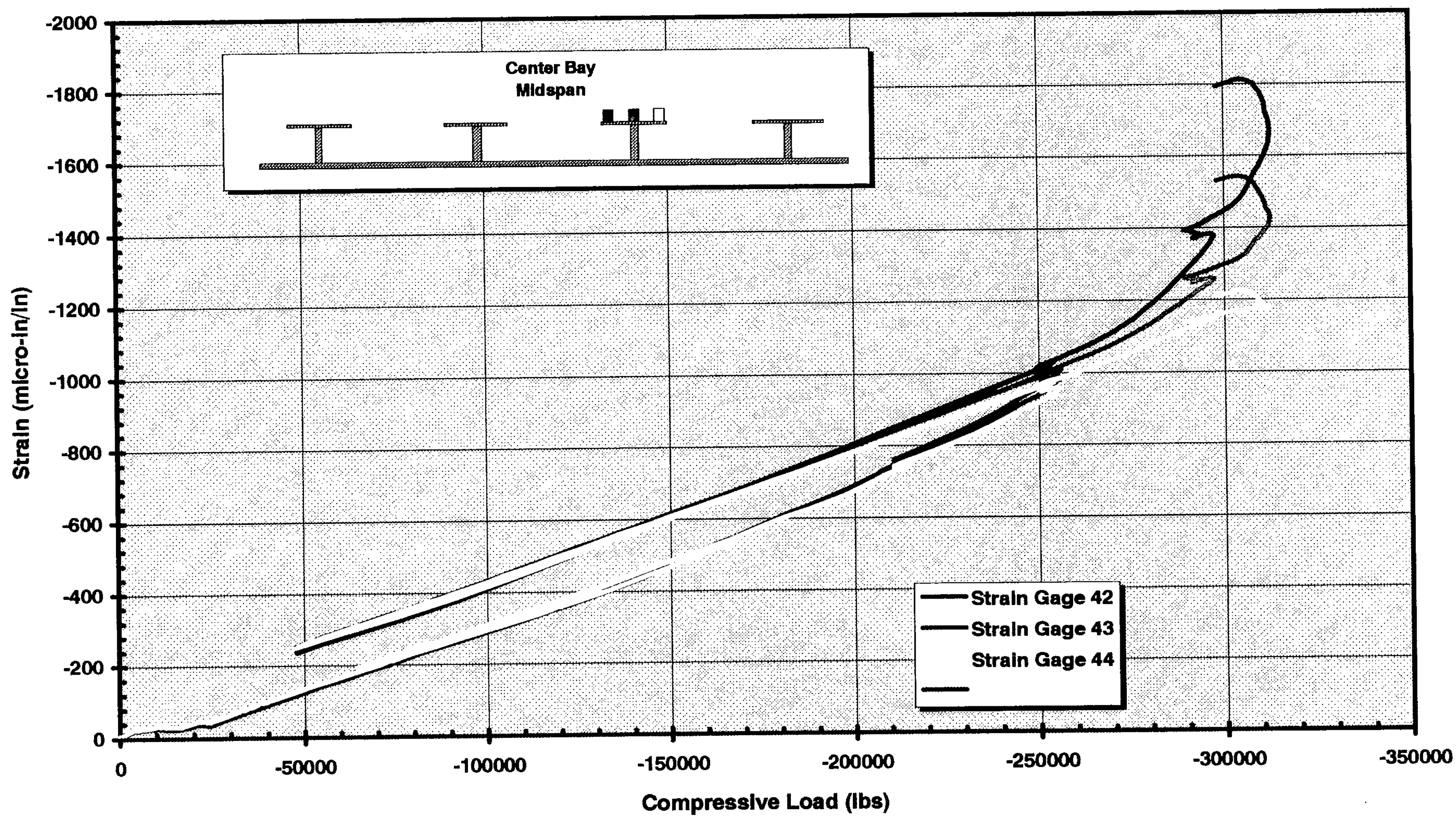
Strain vs. Applied Load



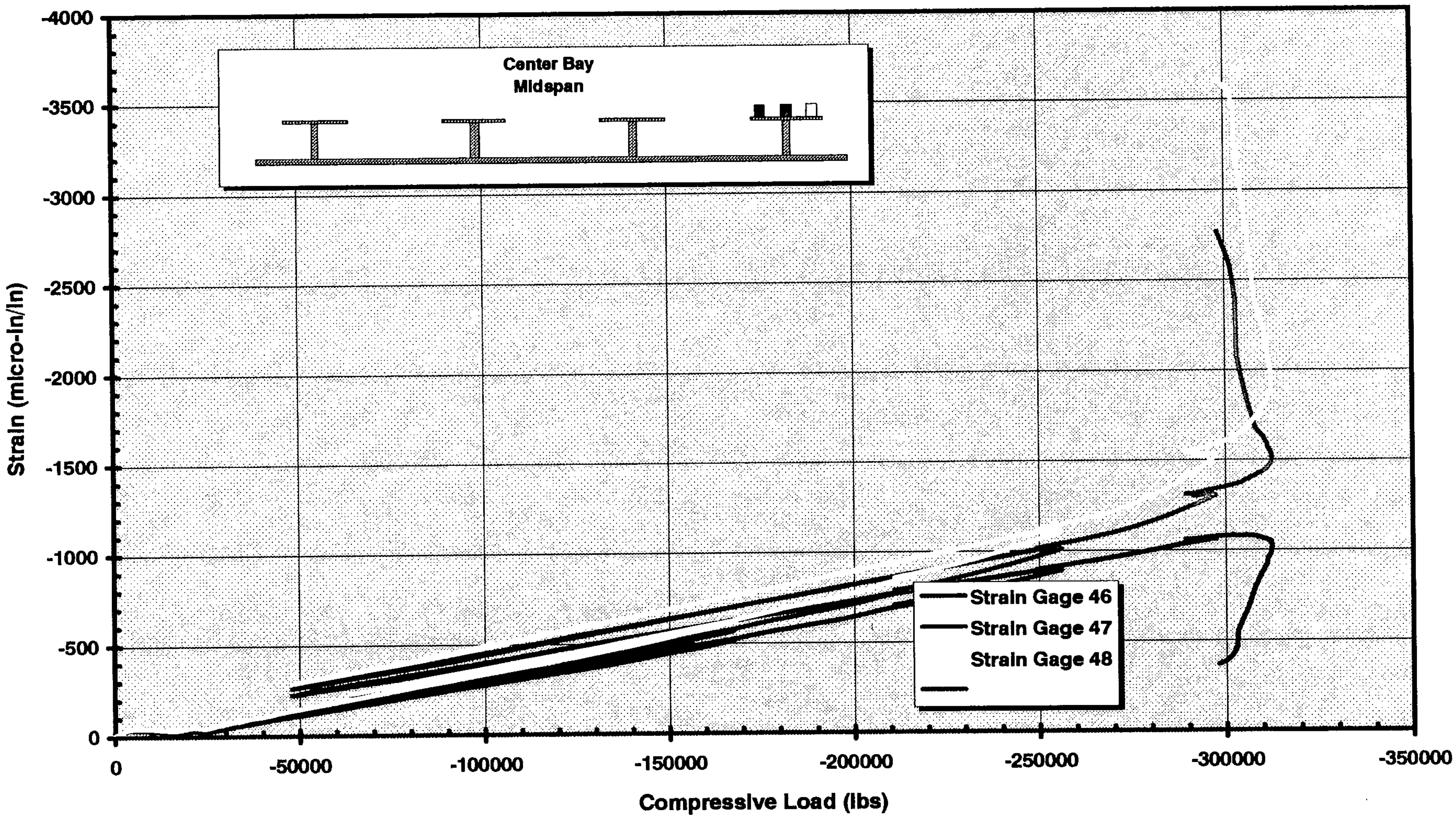
Strain vs. Applied Load

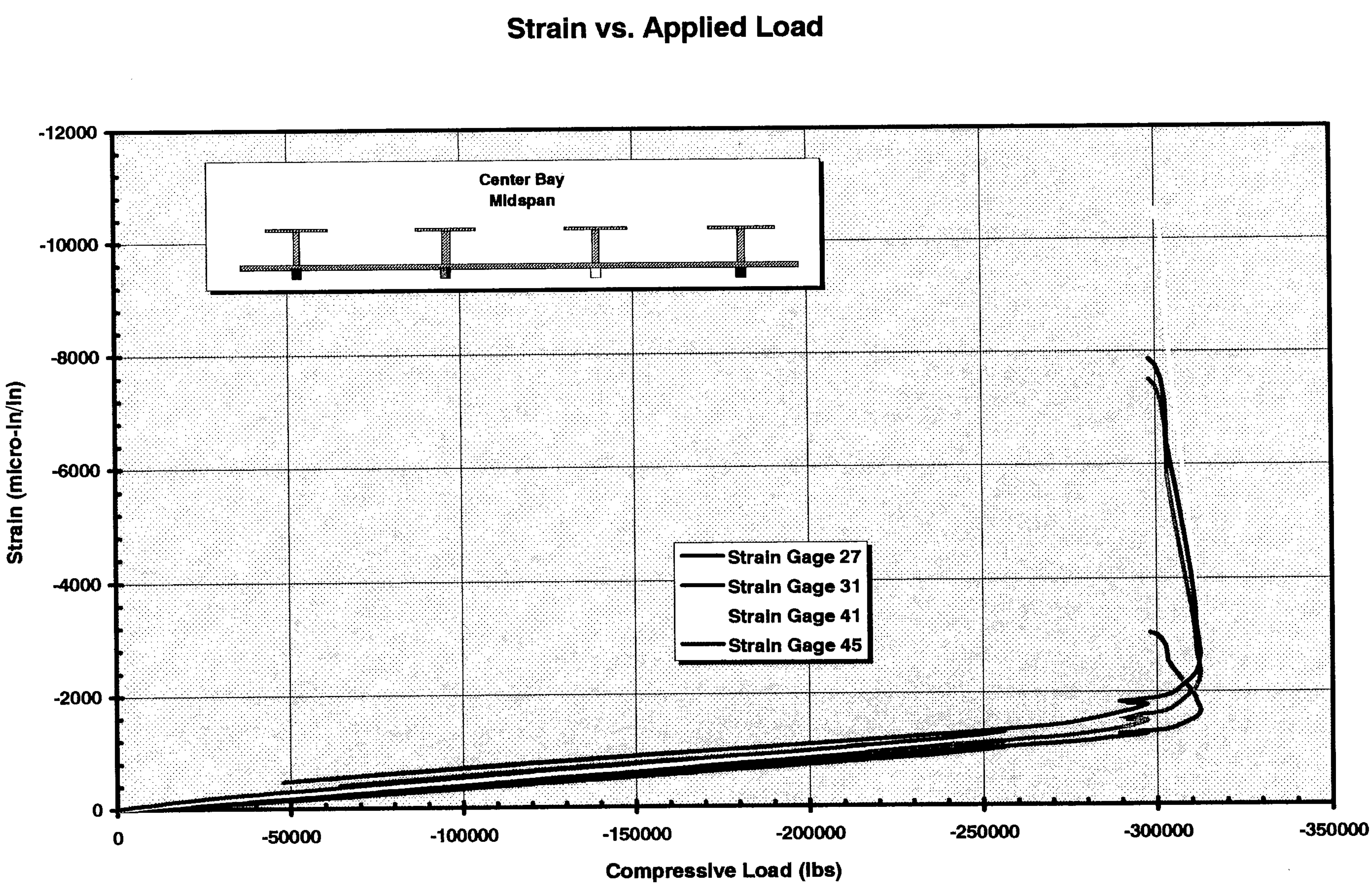


Strain vs. Applied Load

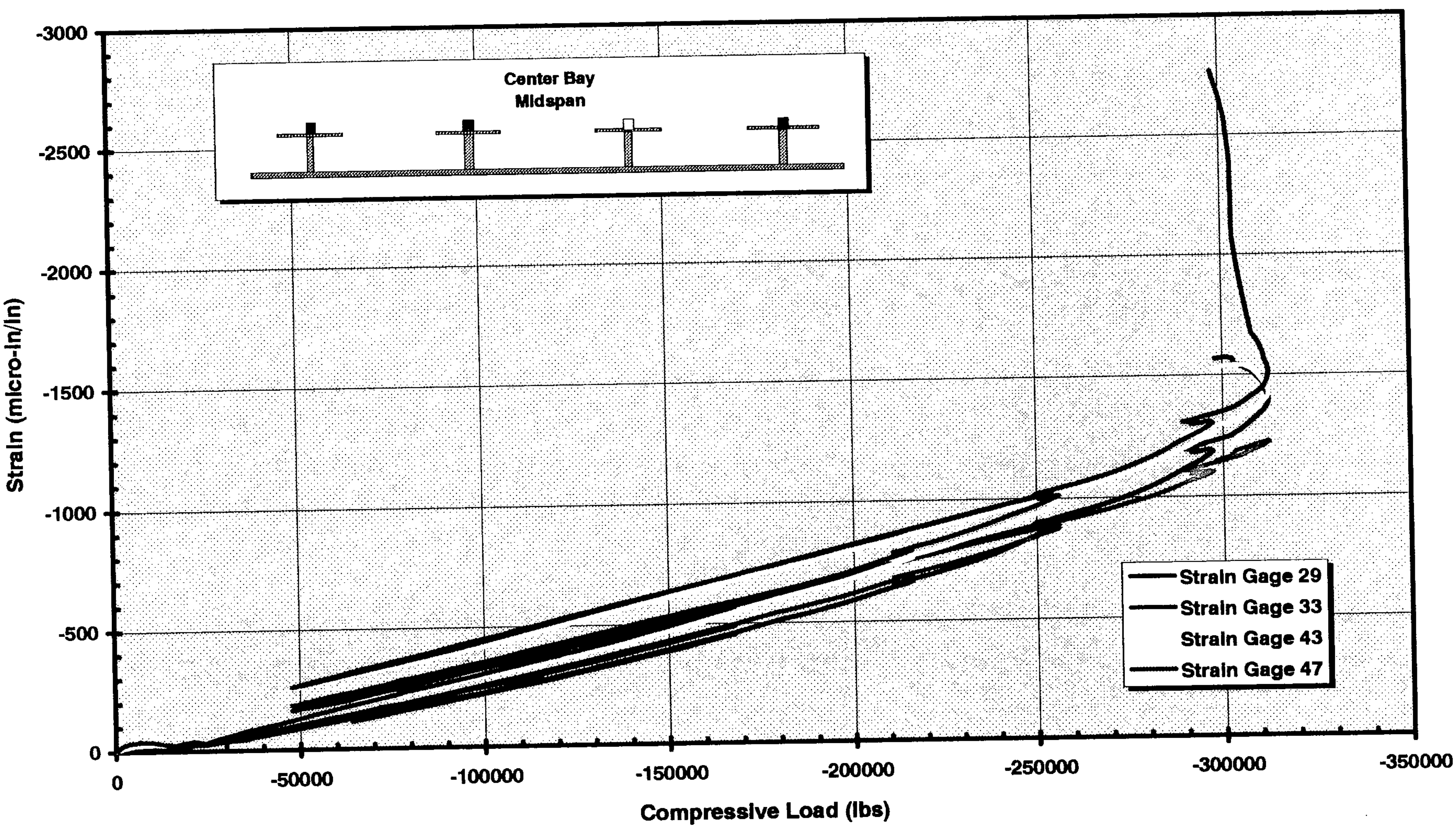


Strain vs. Applied Load

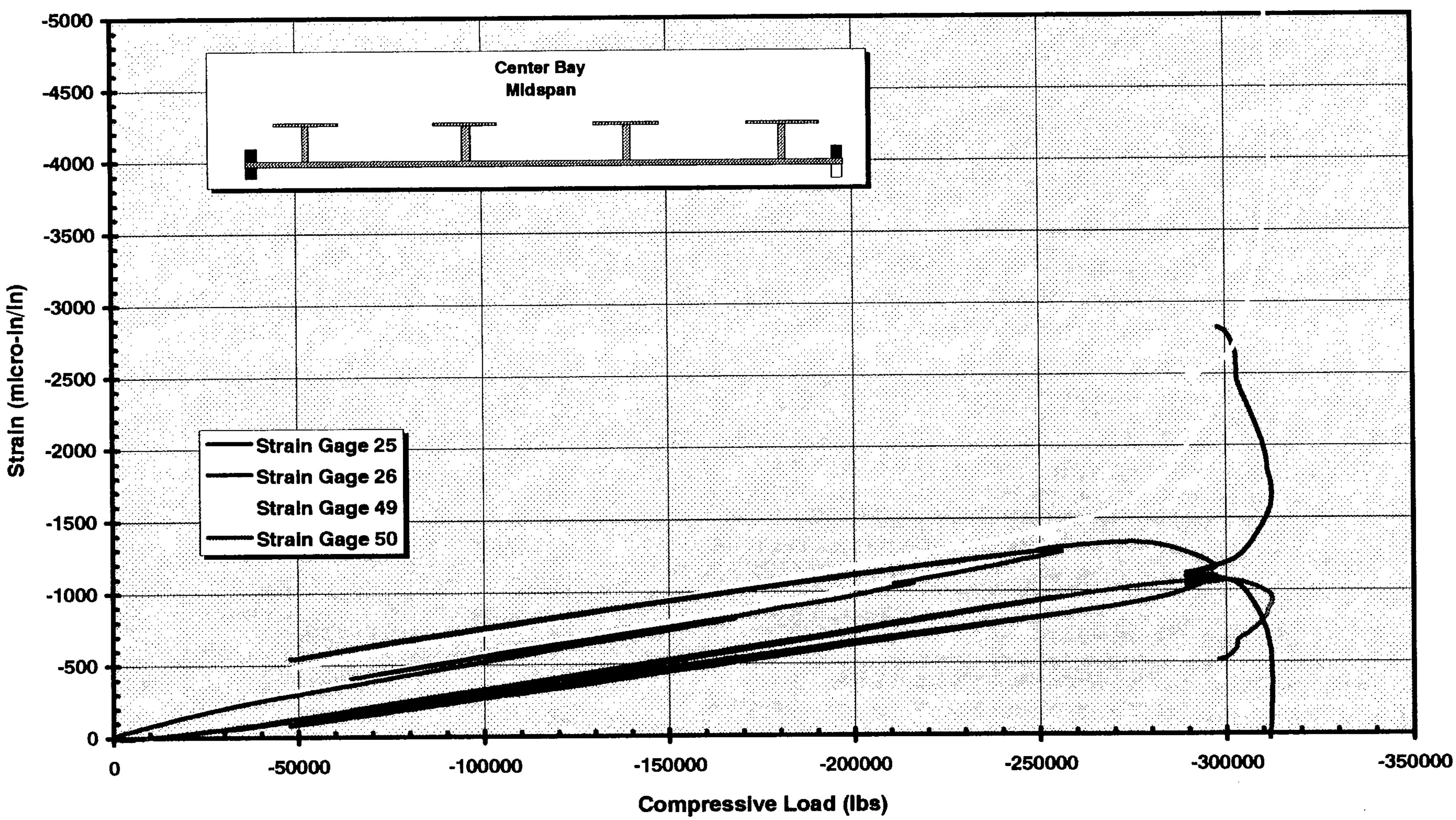



Strain vs. Applied Load
Center Bay
Midspan
Strain Gage 27
Strain Gage 31
Strain Gage 41
Strain Gage 45
-12000
-10000
-8000
-6000
-4000
-2000
0
Strain (micro-in/in)
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)

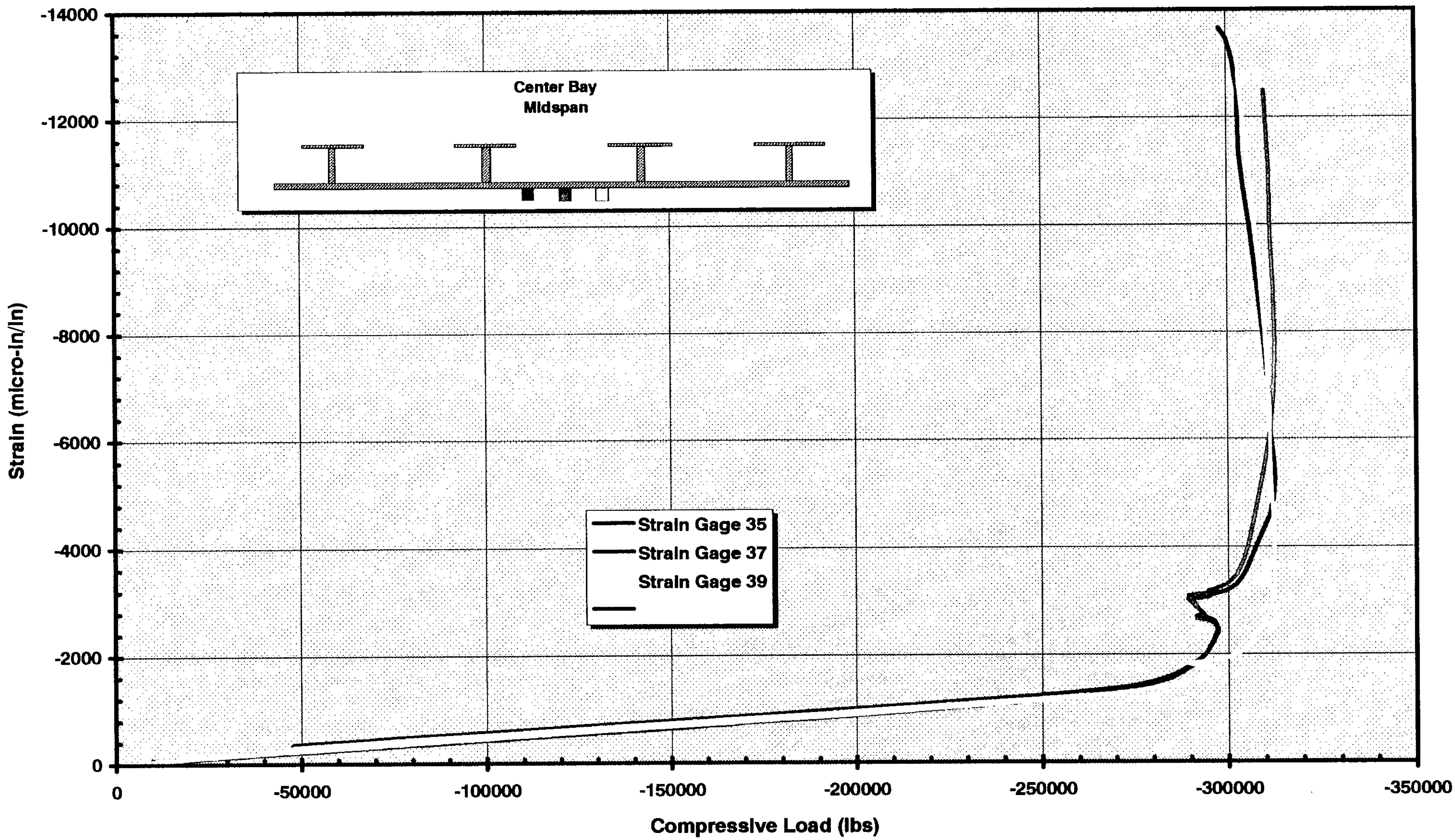
Strain vs. Applied Load



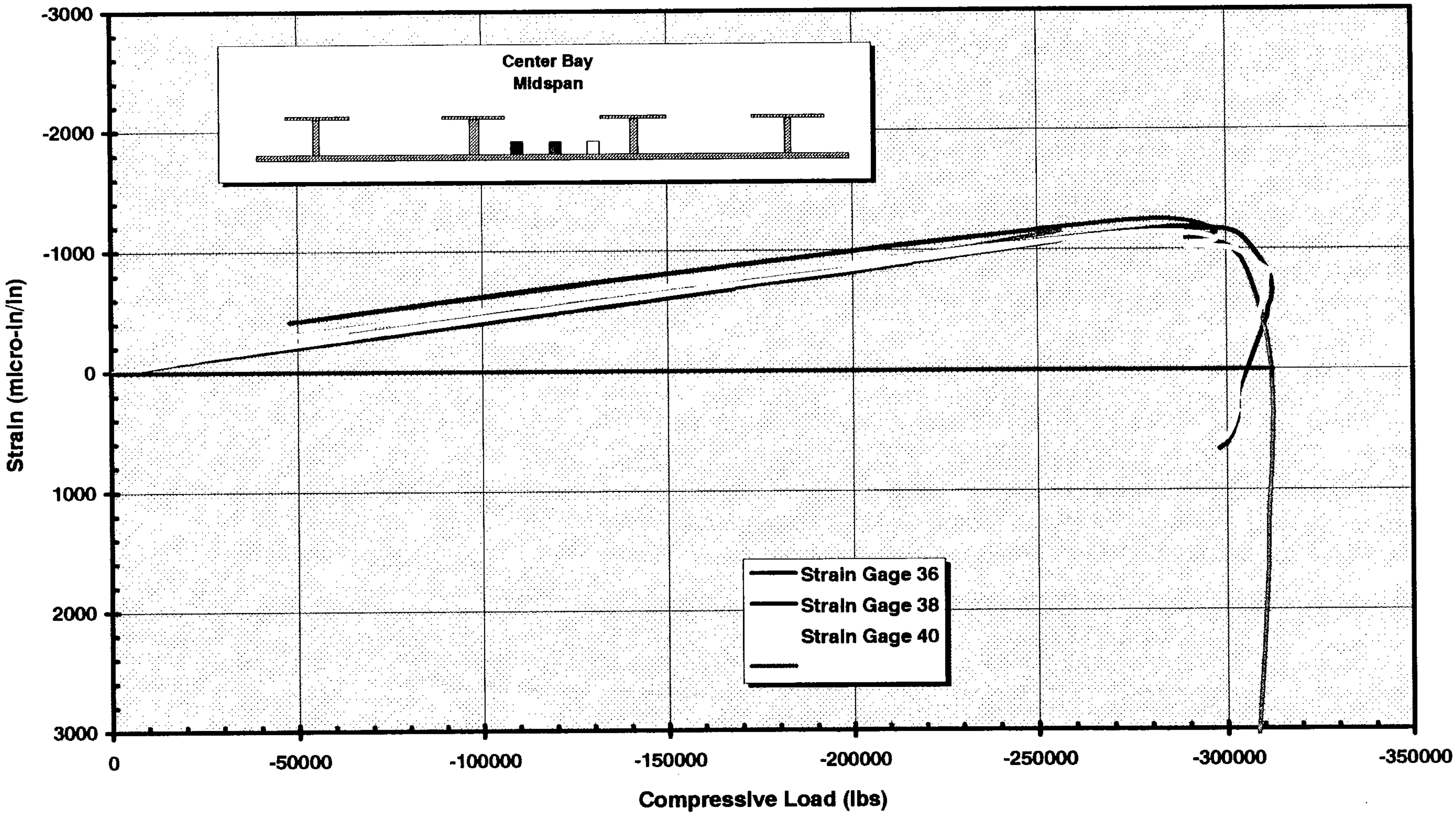
Strain vs. Applied Load



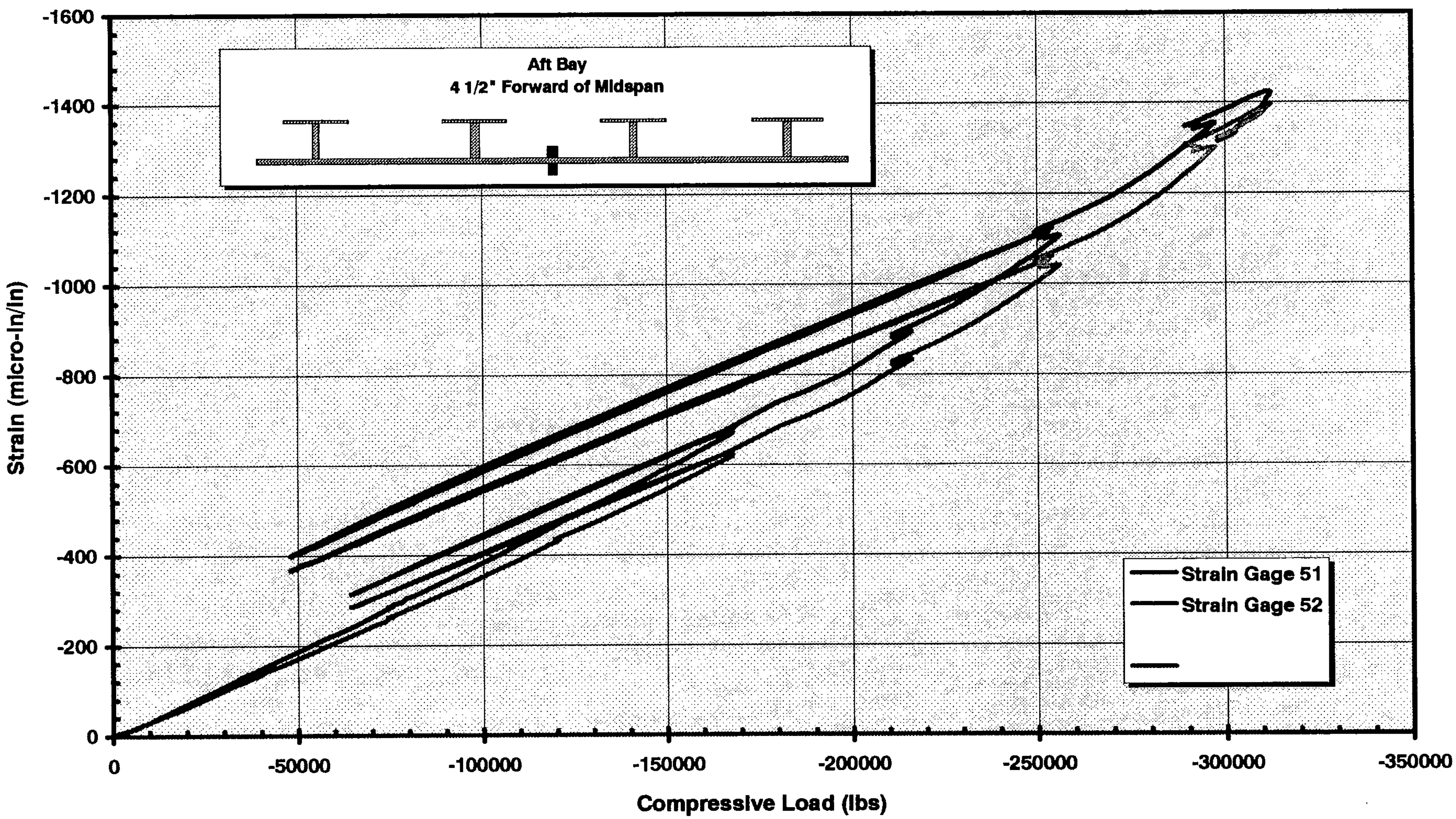
Strain vs. Applied Load



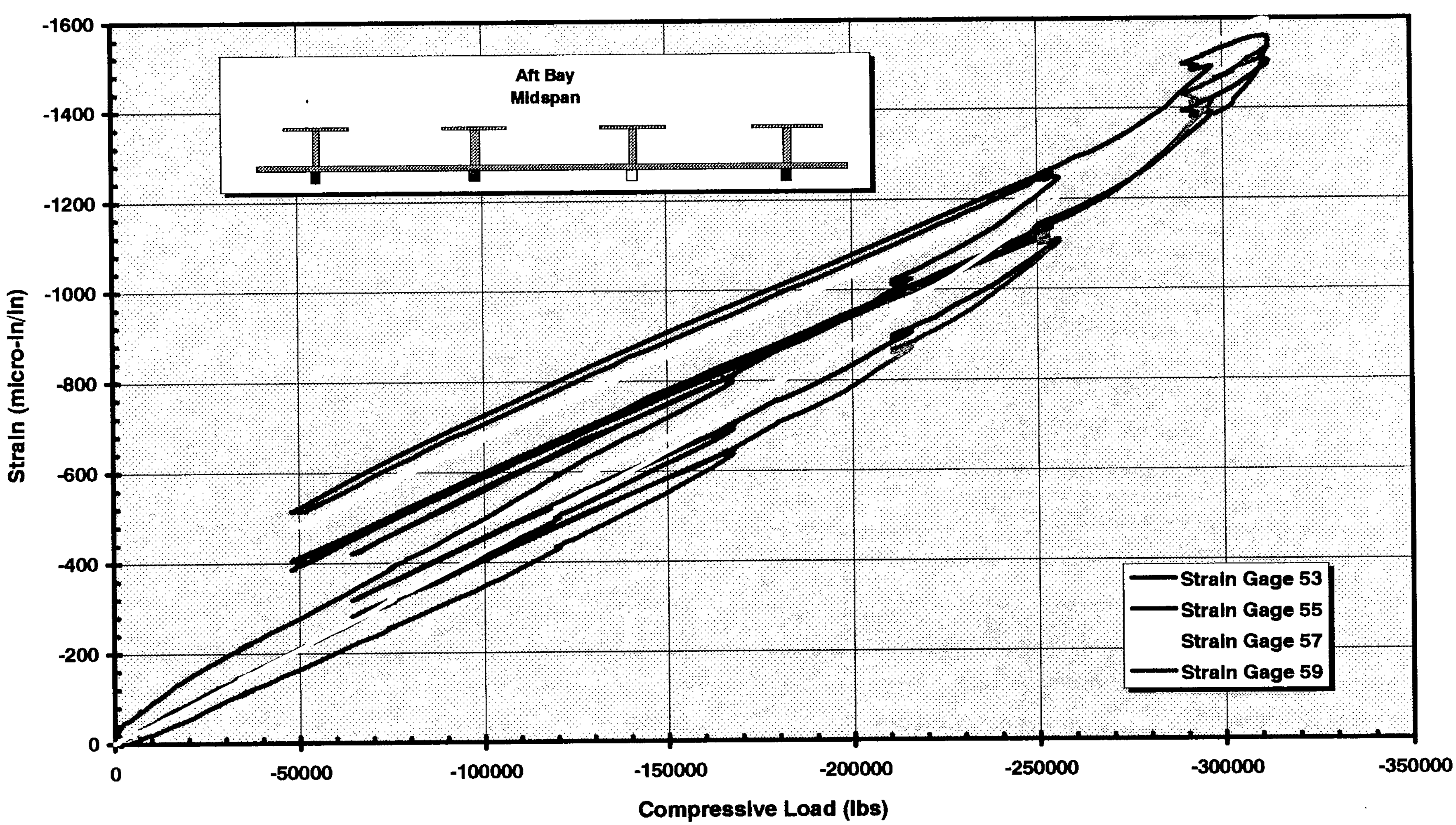
Strain vs. Applied Load



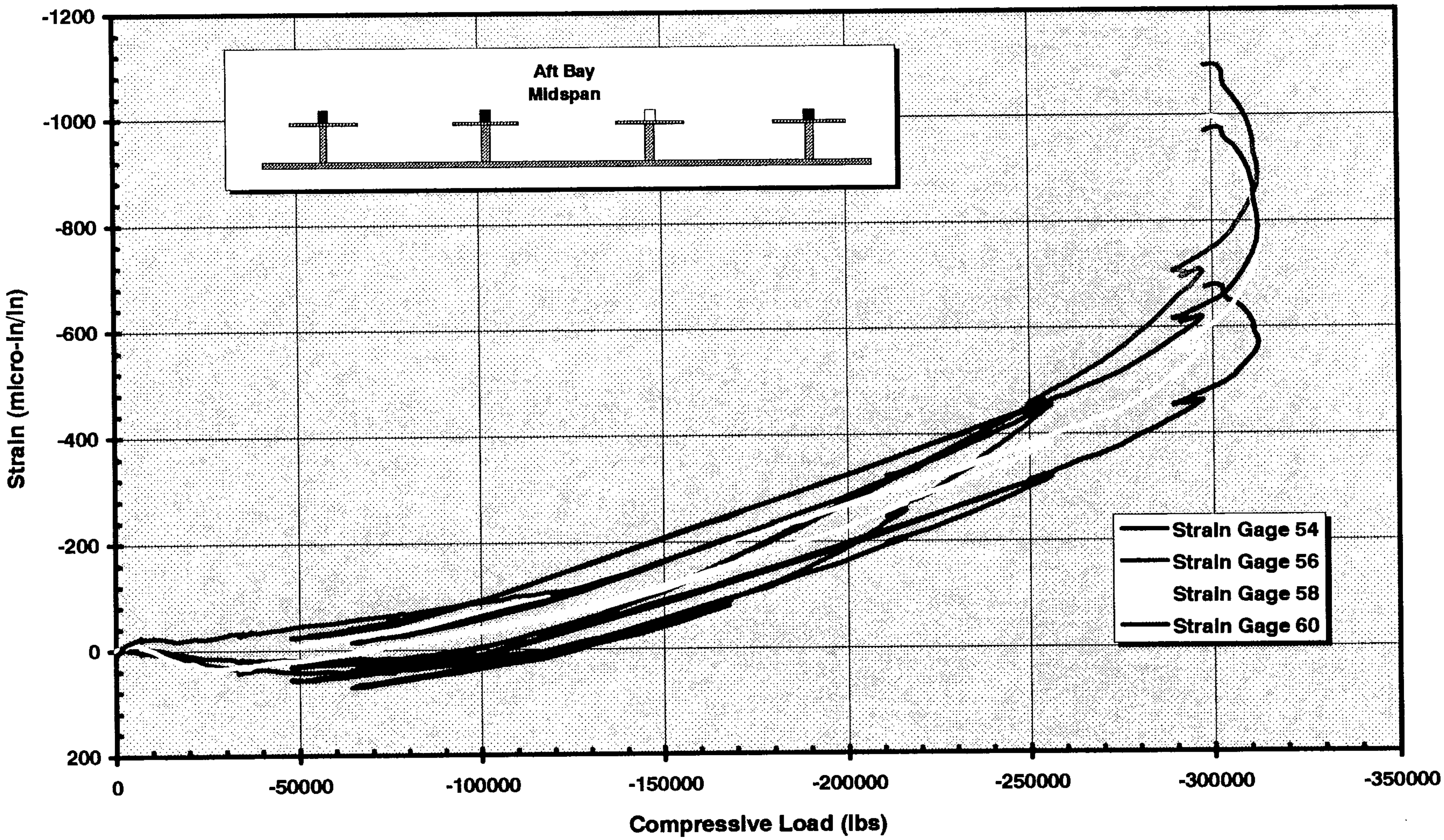
Strain vs. Applied Load



Strain vs. Applied Load

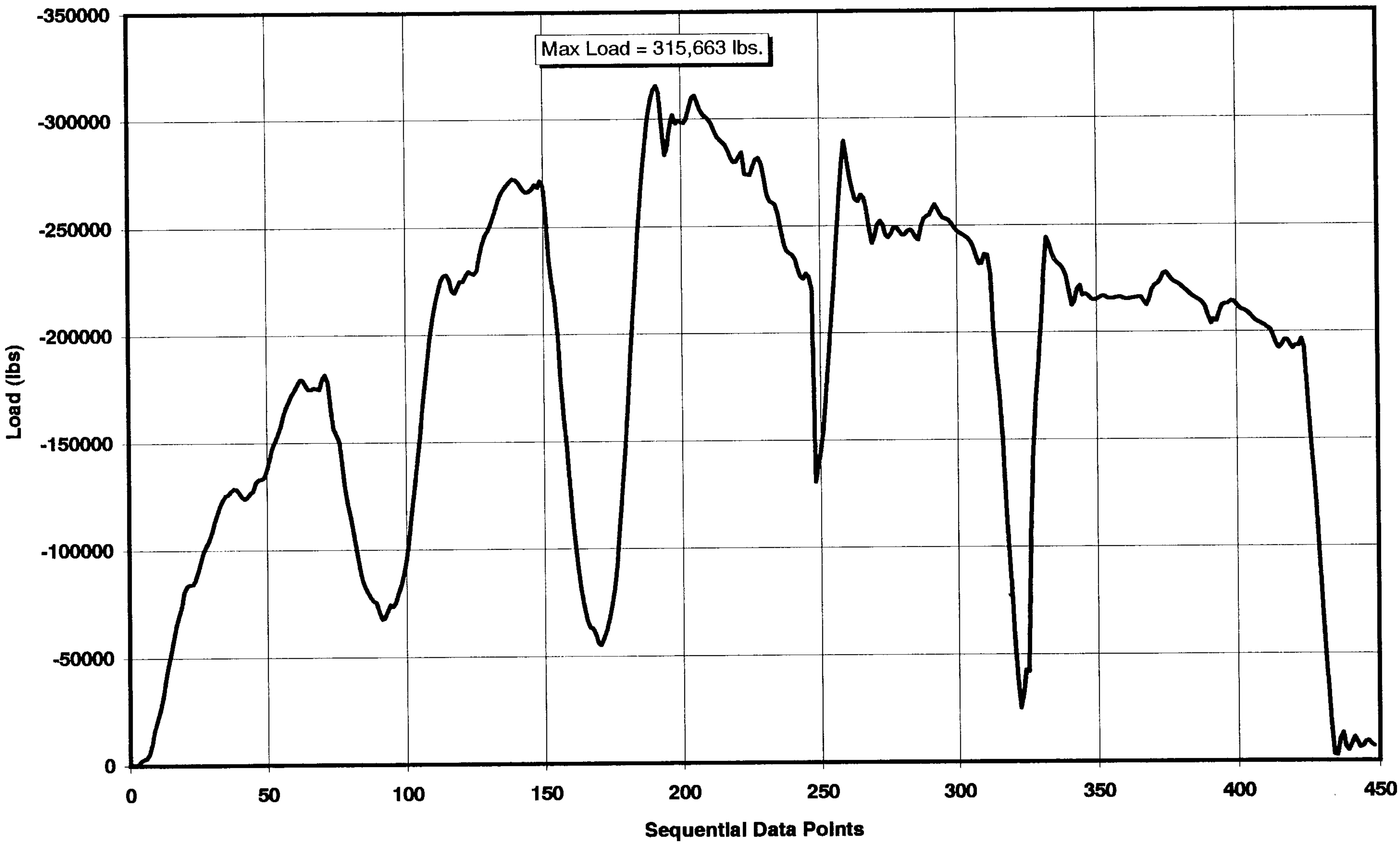


Strain vs. Applied Load

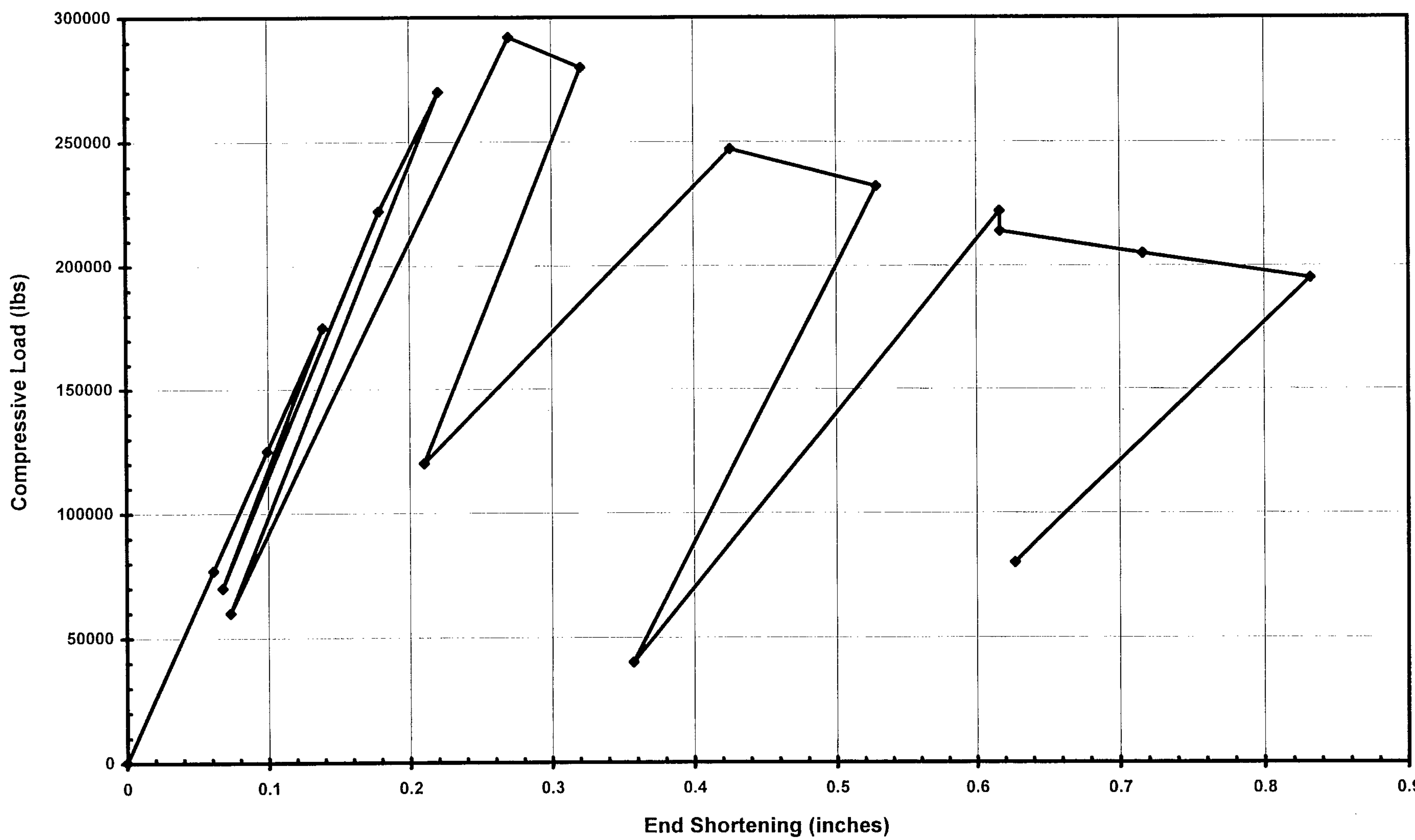


Specimen 0595   Axial and Lateral Load

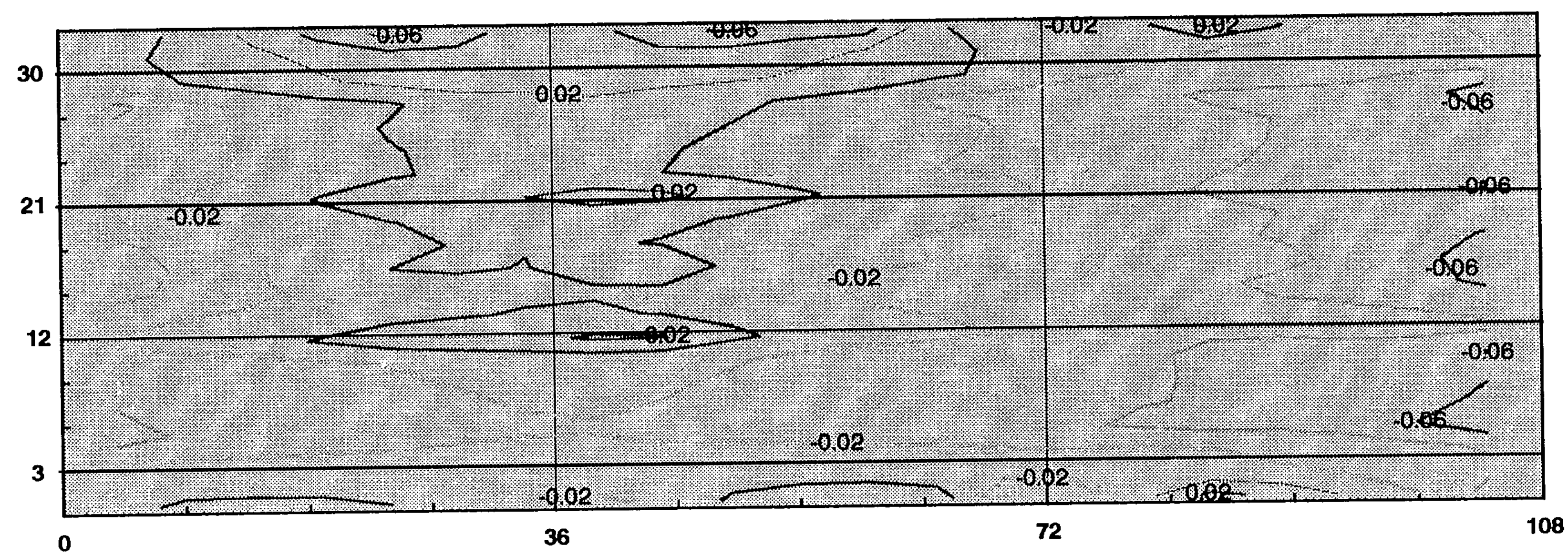
Load History



Load vs End Shortening



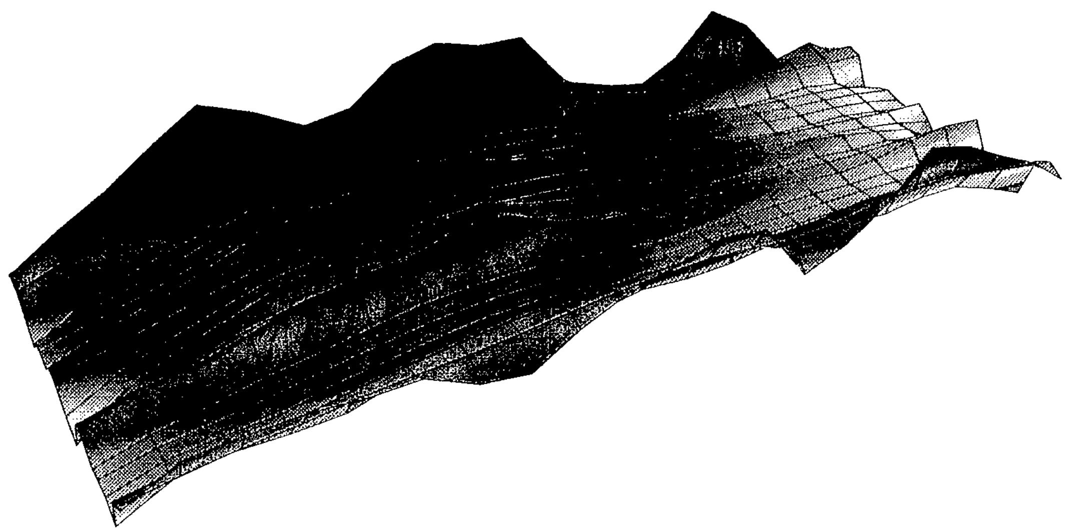
Pre-Test Survey



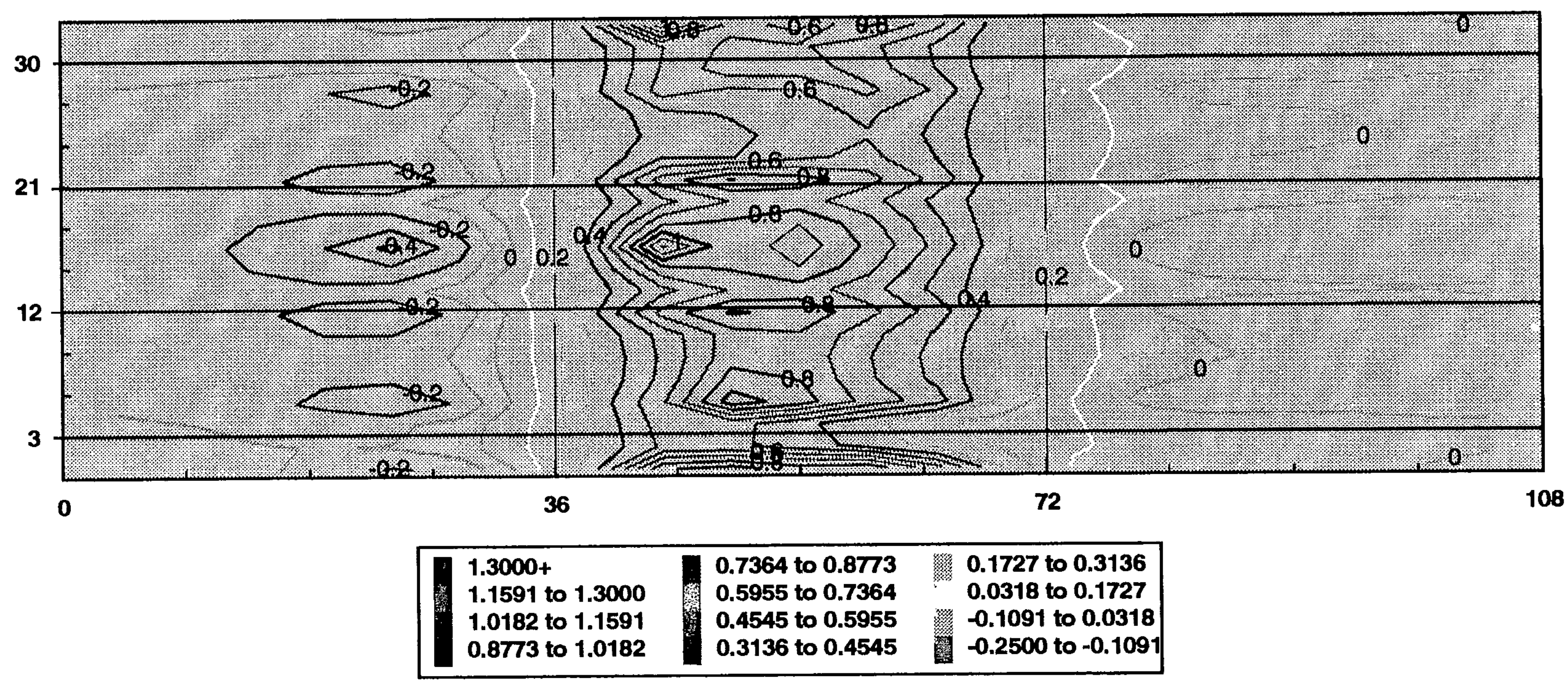
0.1000+	0.0391 to 0.0543	-0.0218 to -0.0066
0.0848 to 0.1000	0.0239 to 0.0391	-0.0370 to -0.0218
0.0695 to 0.0848	0.0086 to 0.0239	-0.0523 to -0.0370
0.0543 to 0.0695	-0.0066 to 0.0086	-0.0675 to -0.0523

All measurements are in inches

Pre-Test Survey

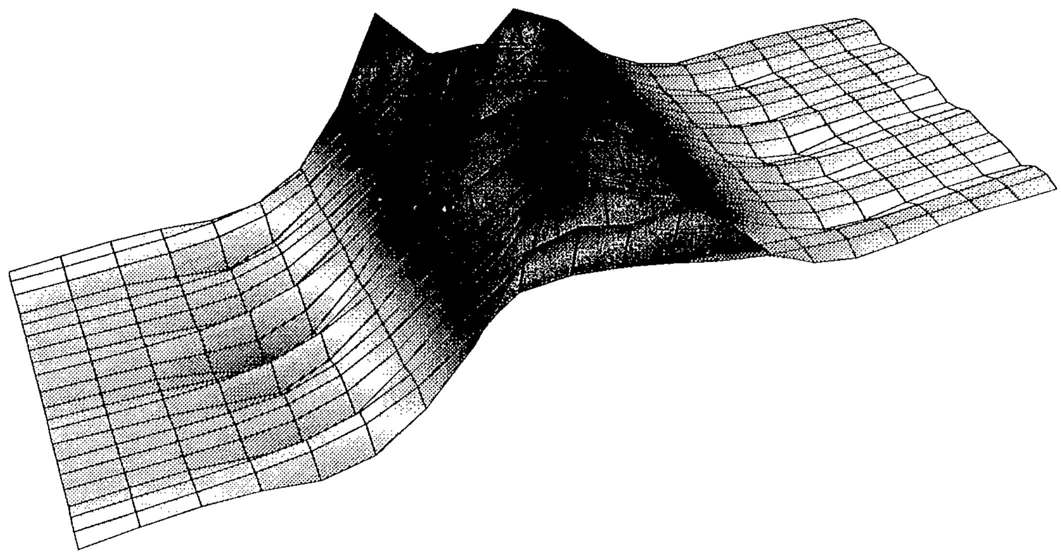


Post-Test Survey

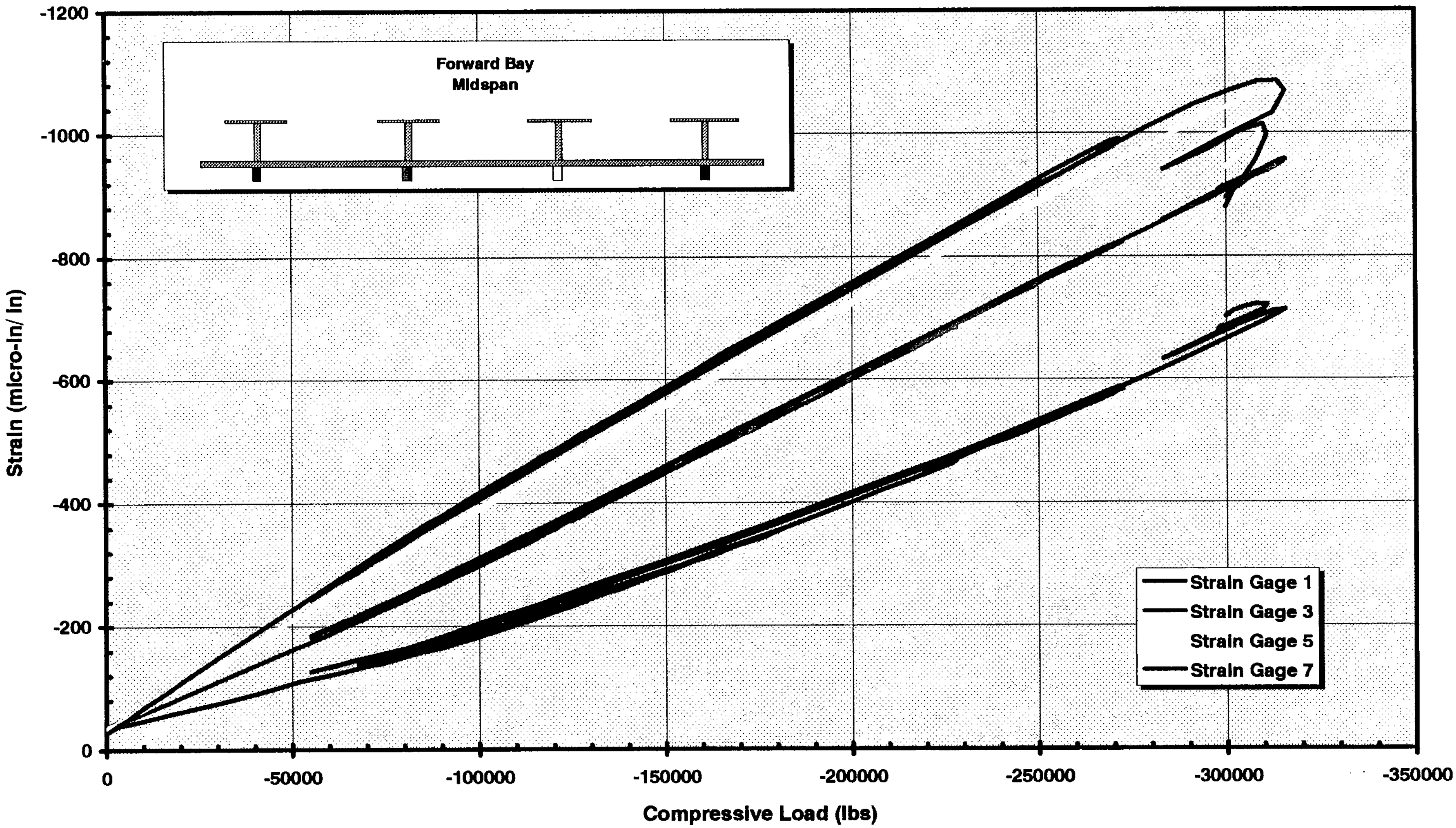


All measurements are in inches

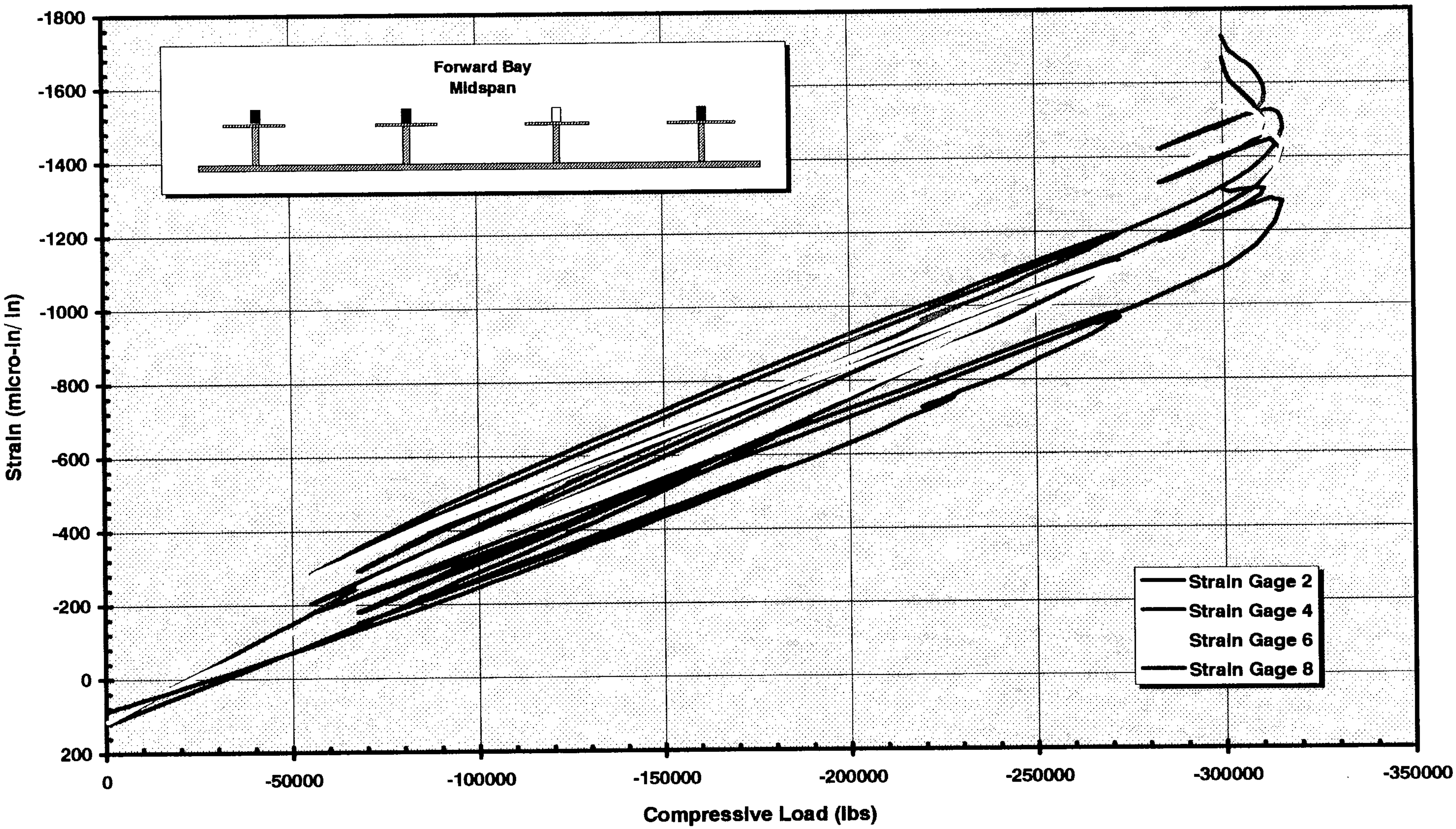
Post-Test Survey



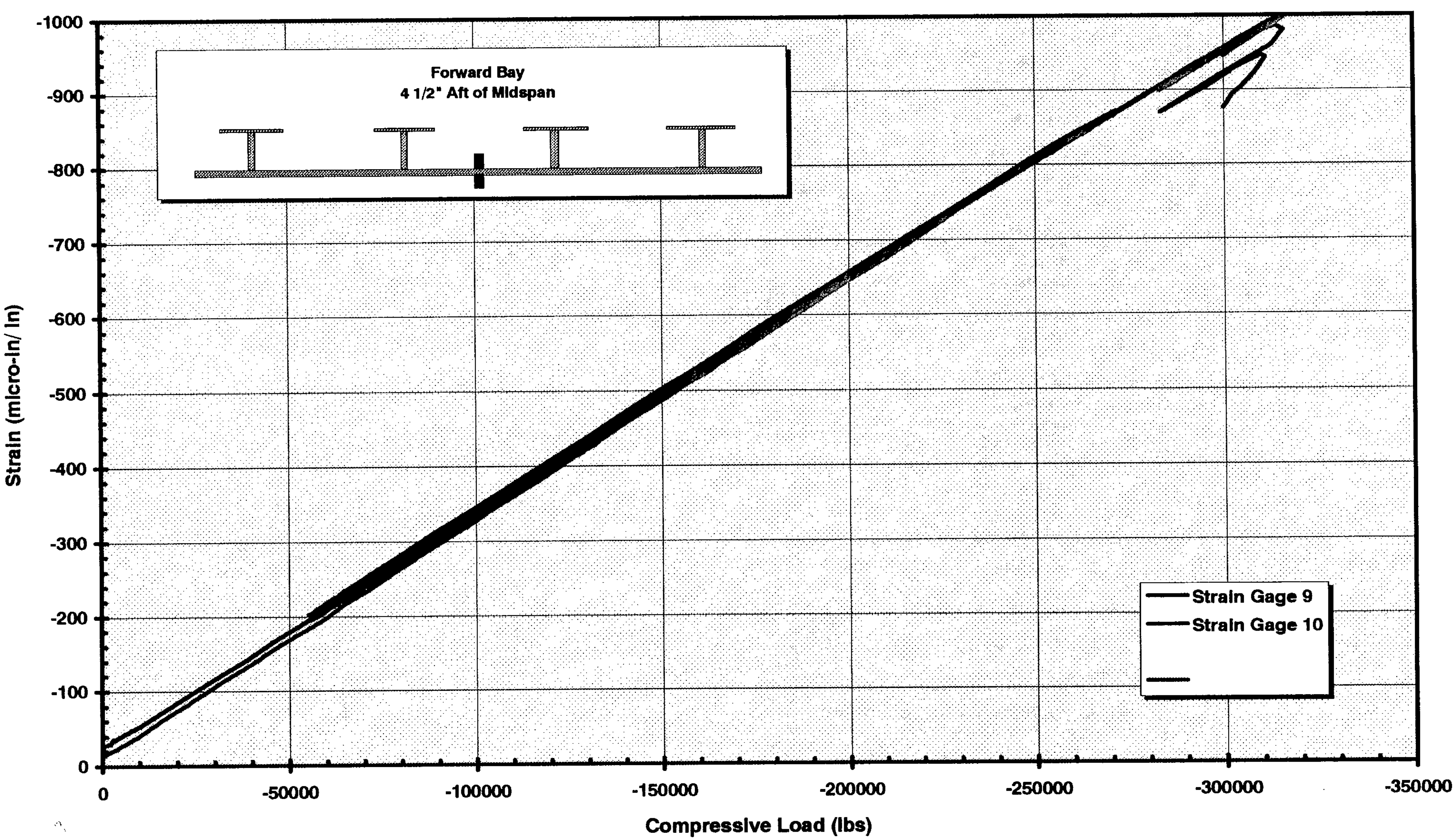
Strain vs. Load



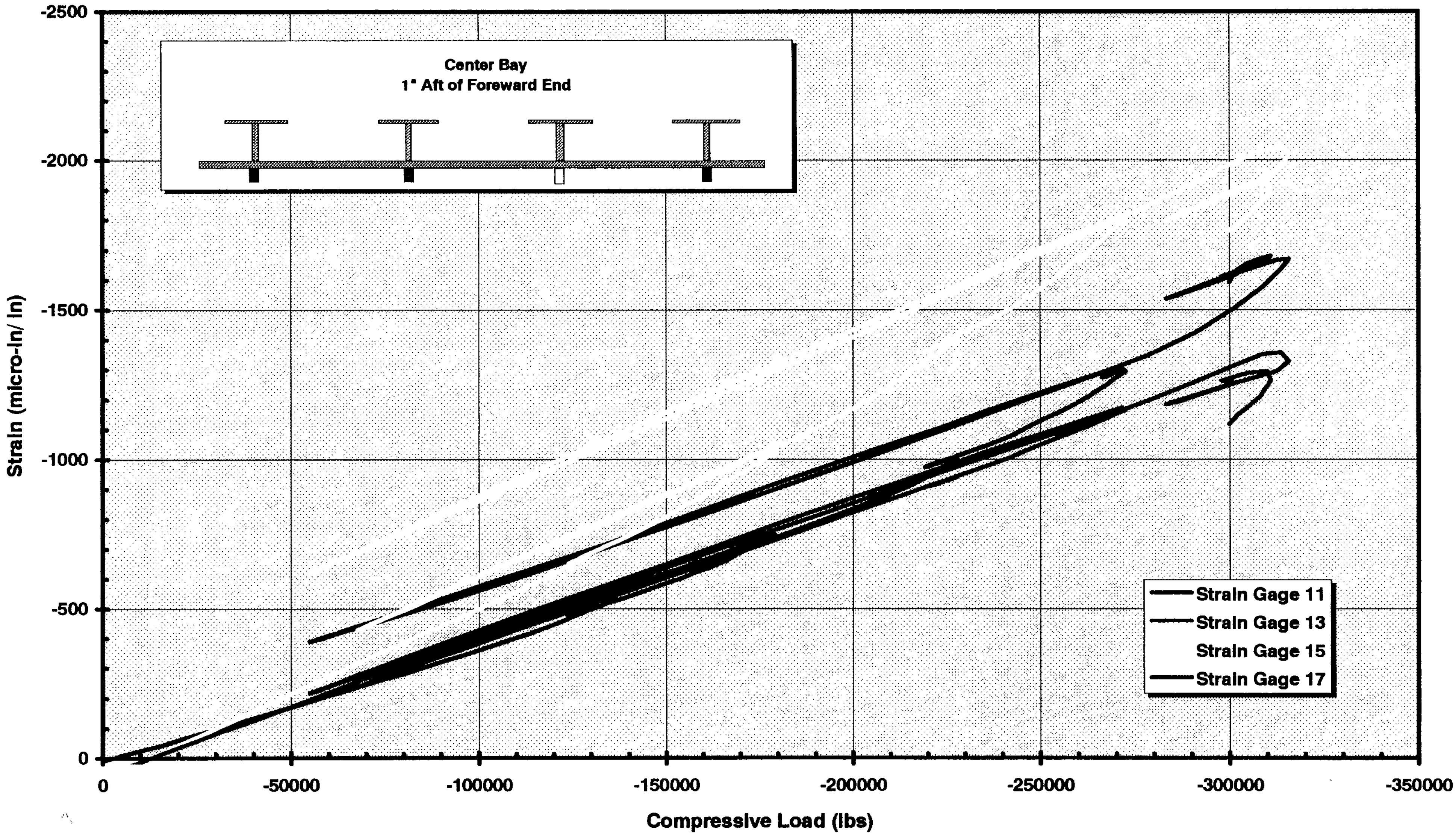
Strain vs. Load



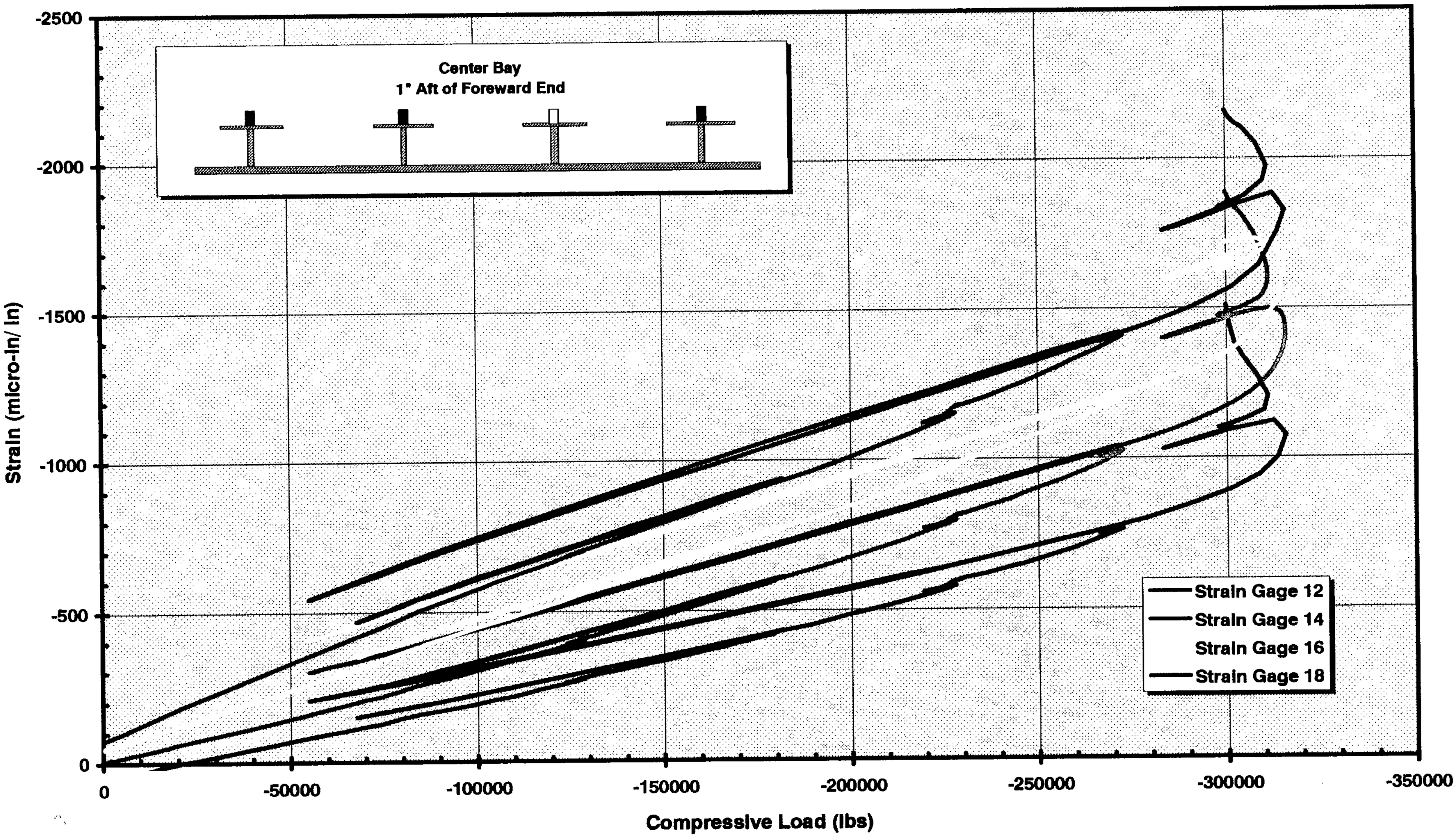
Strain vs. Applied Load



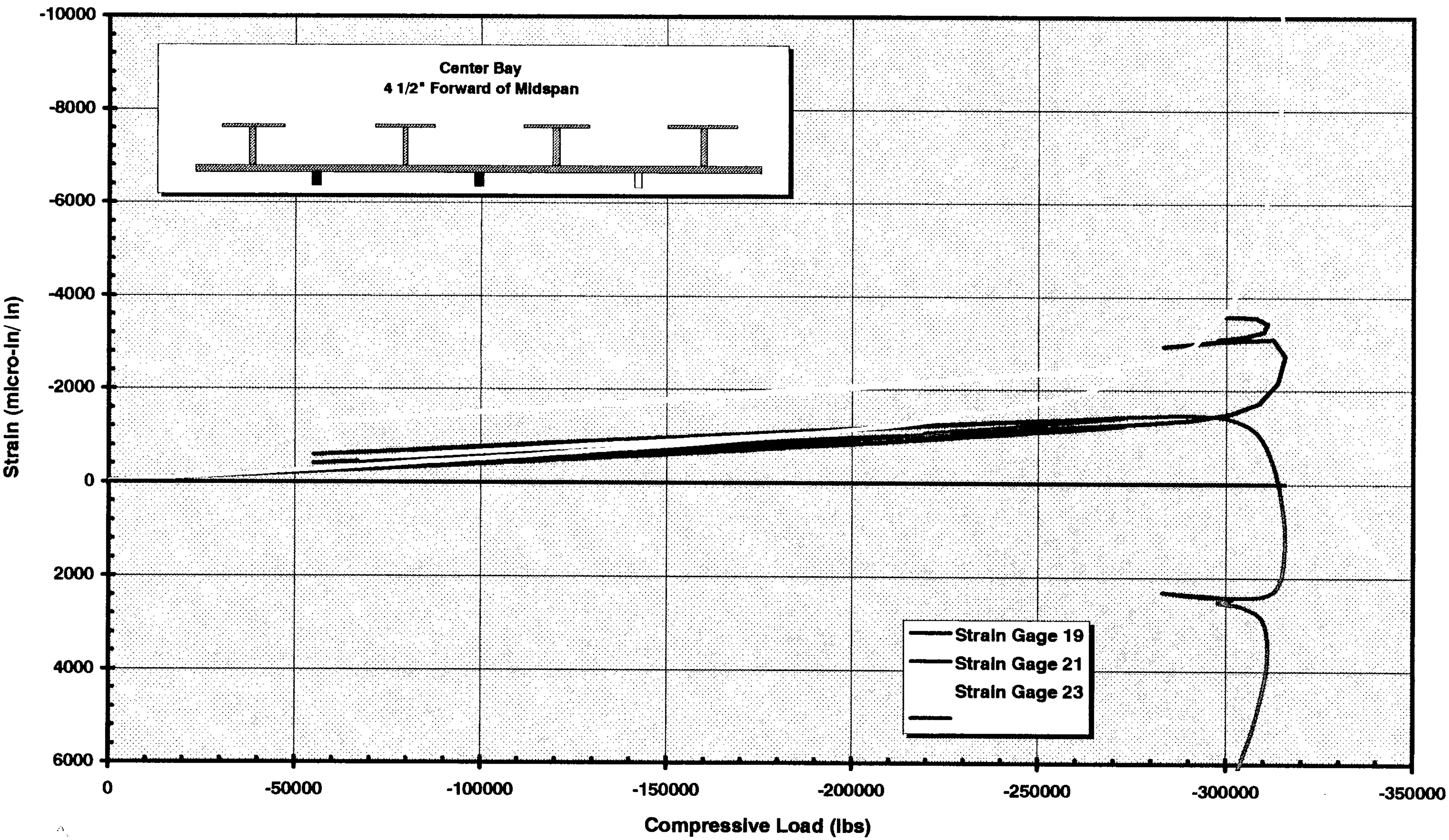
Strain vs. Applied Load



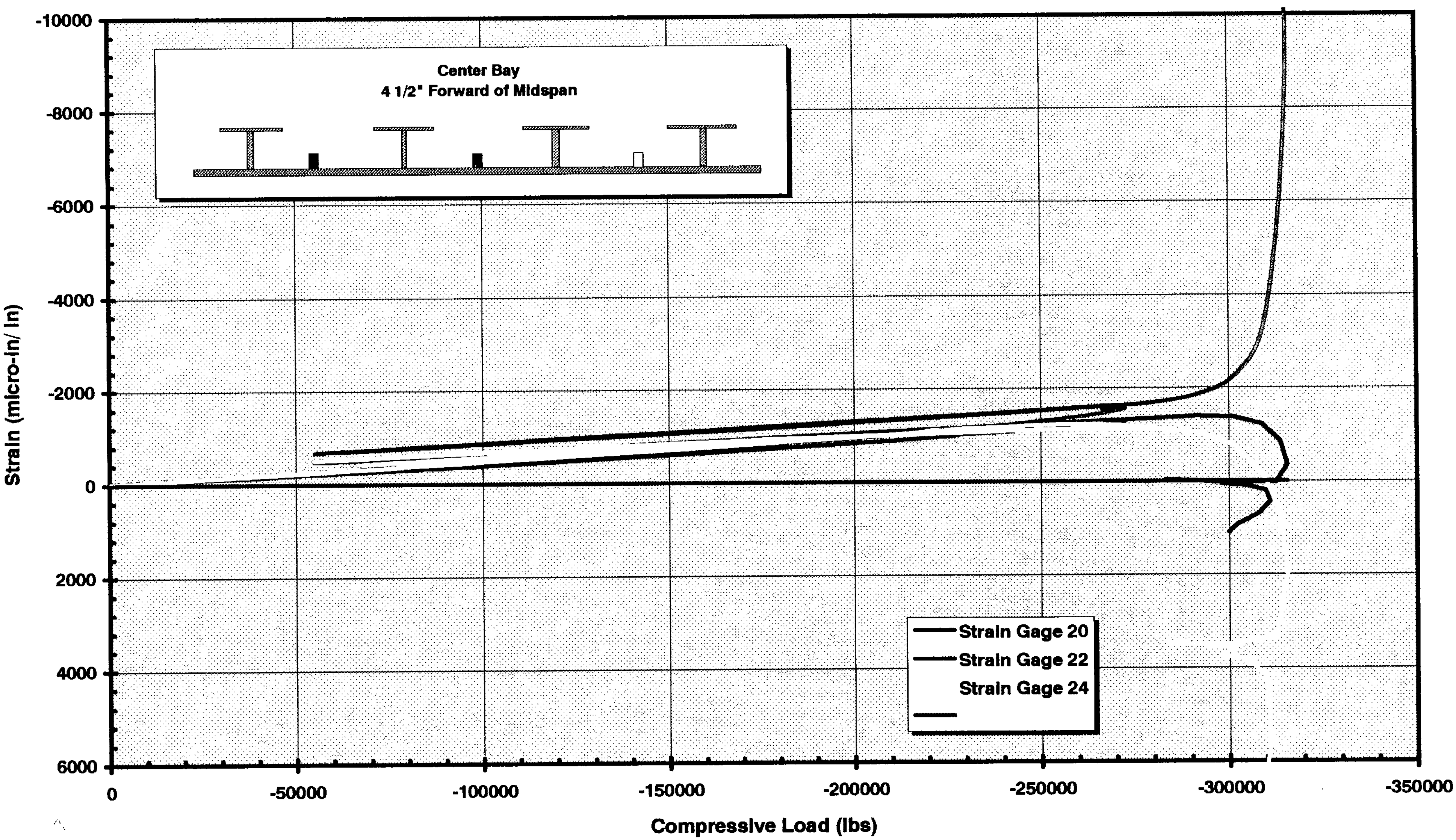
Strain vs. Applied Load



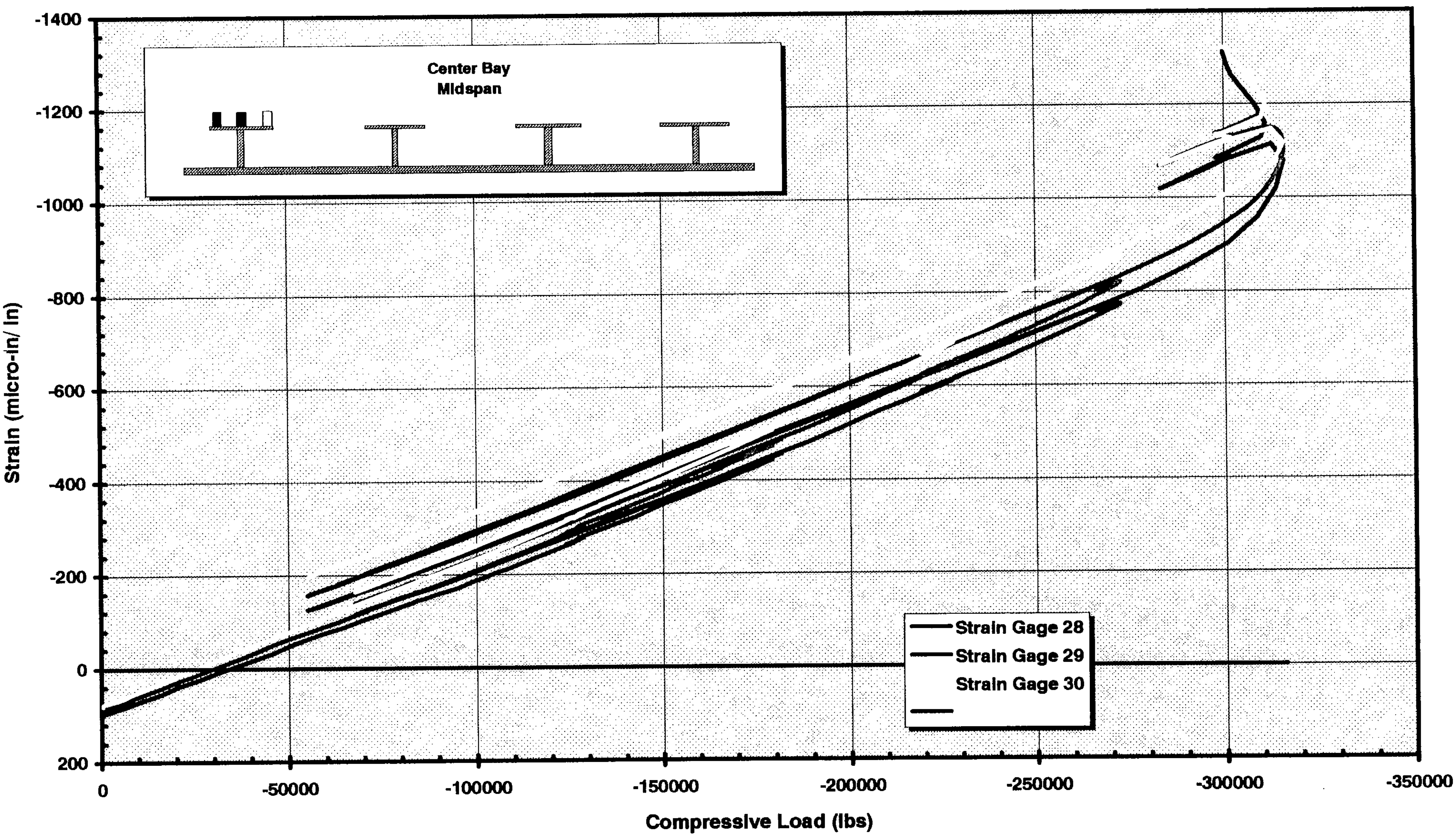
Strain vs. Applied Load



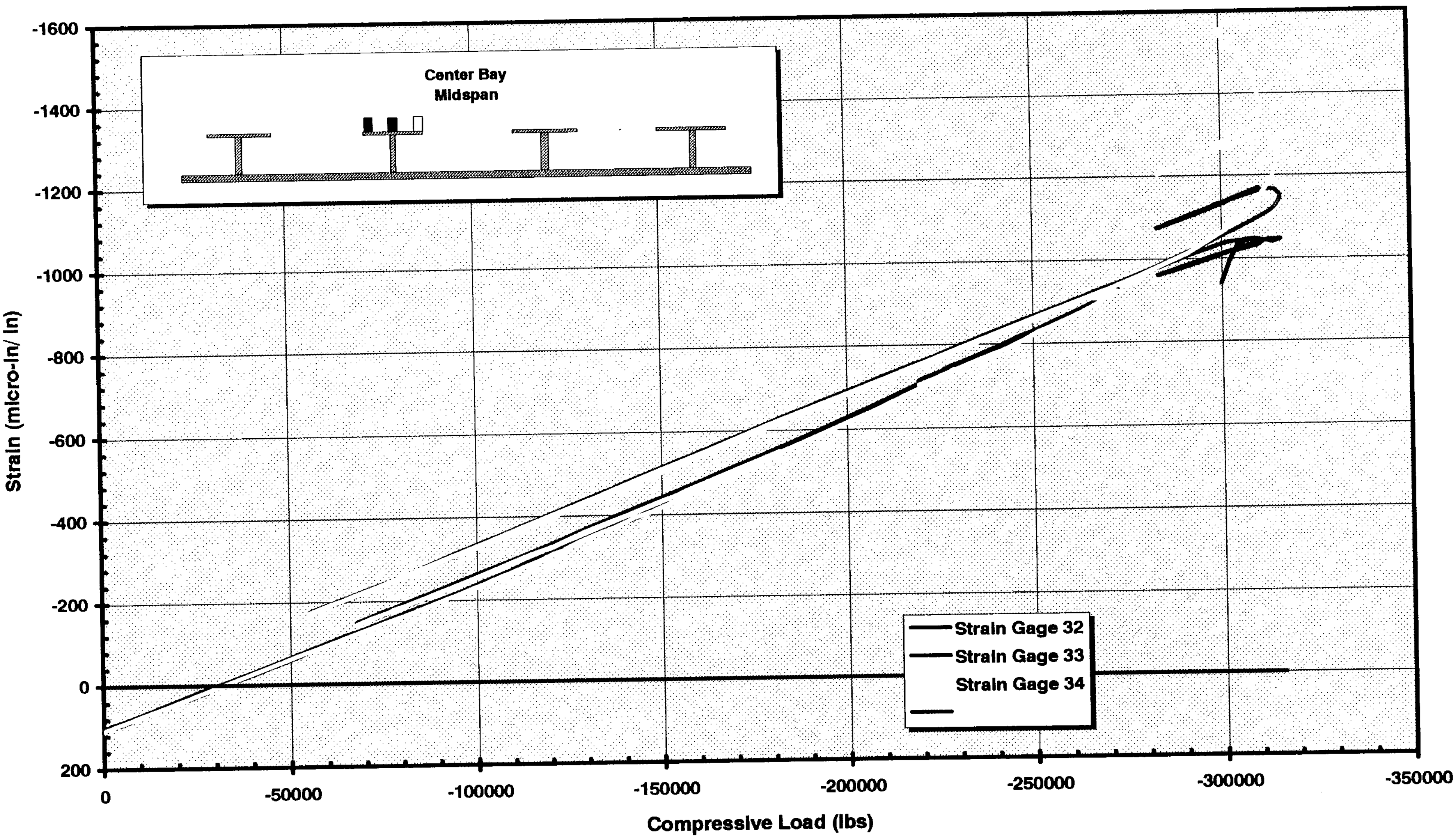
Strain vs. Applied Load



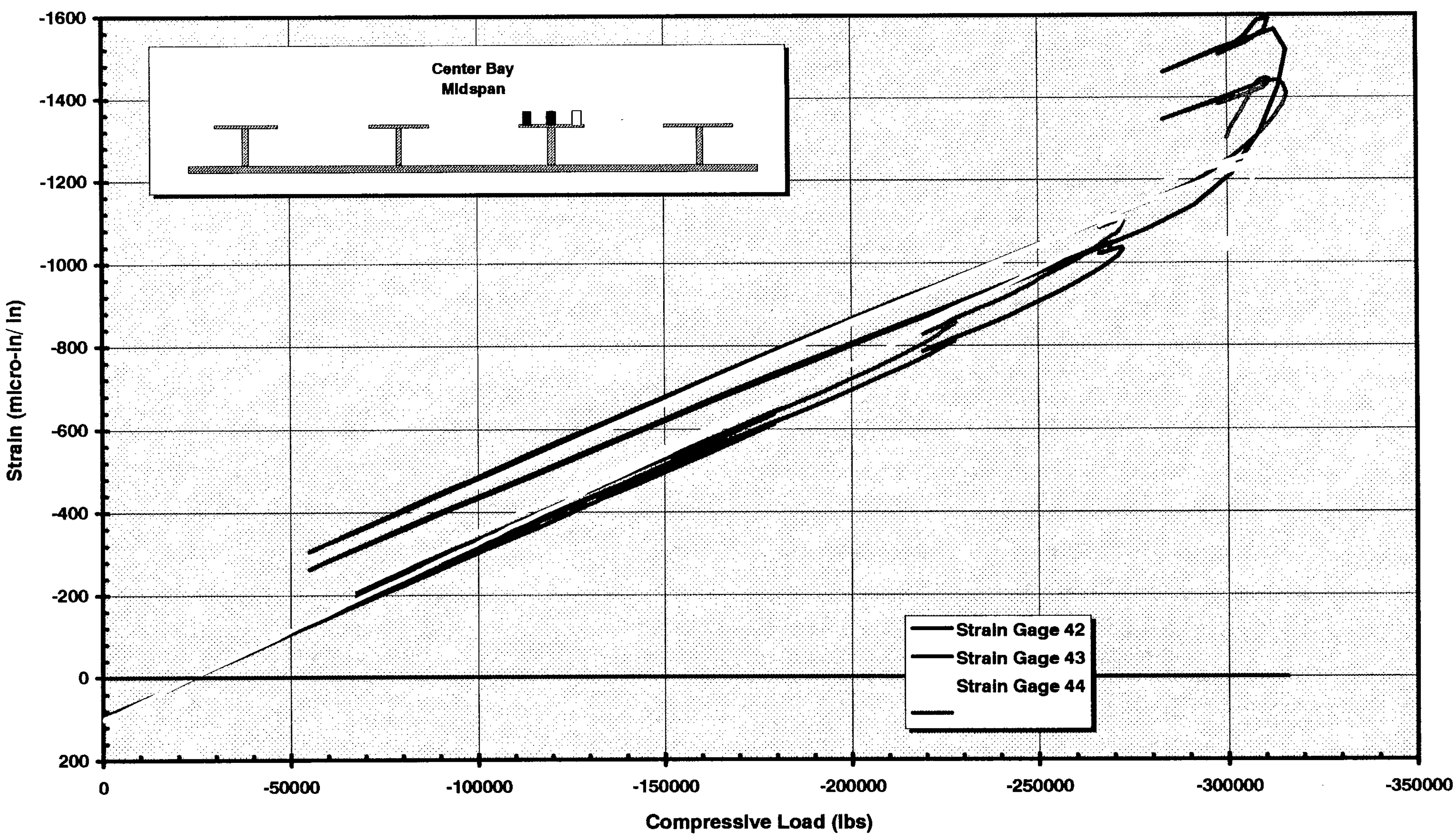
Strain vs. Applied Load



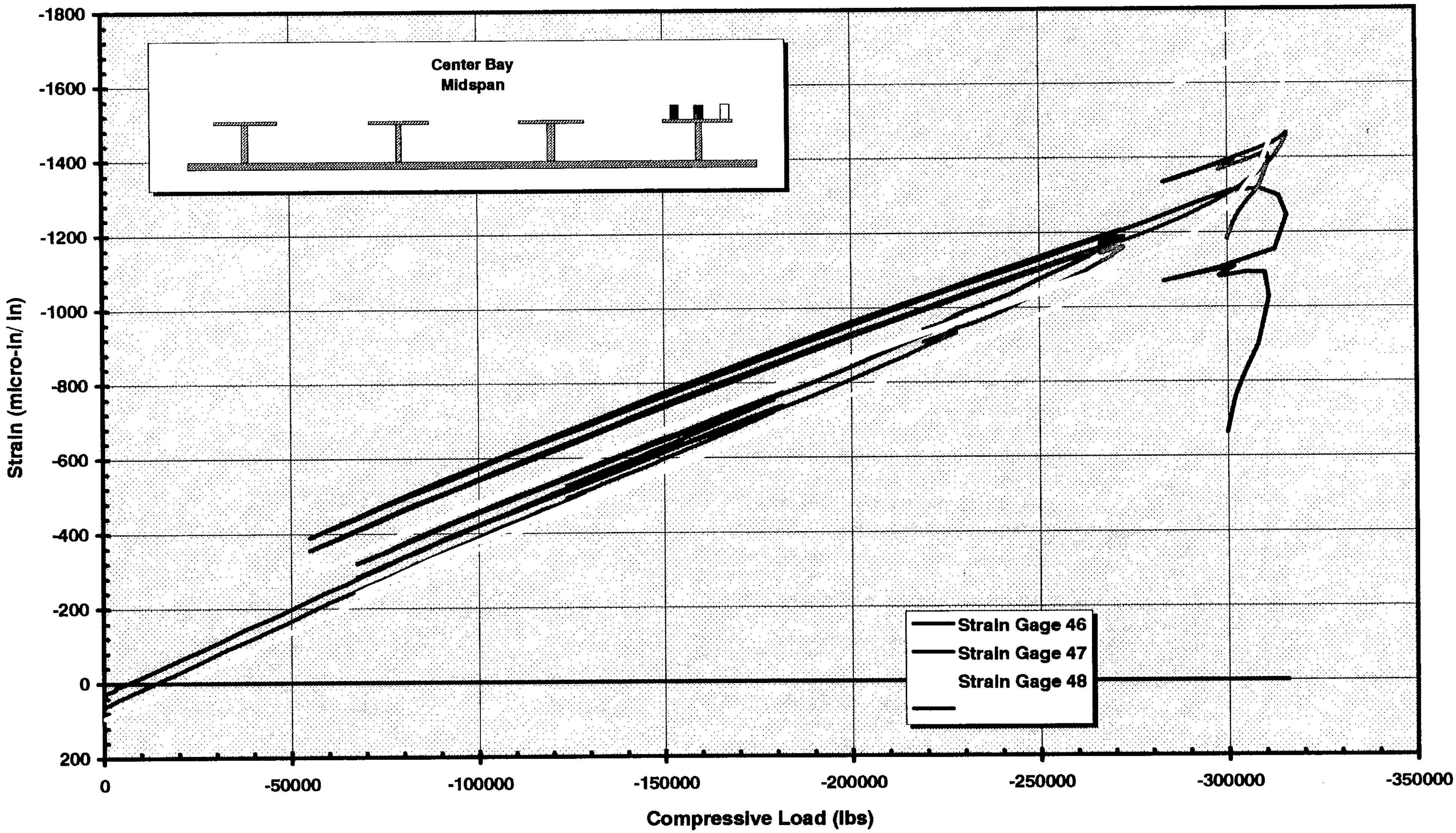
Strain vs. Applied Load



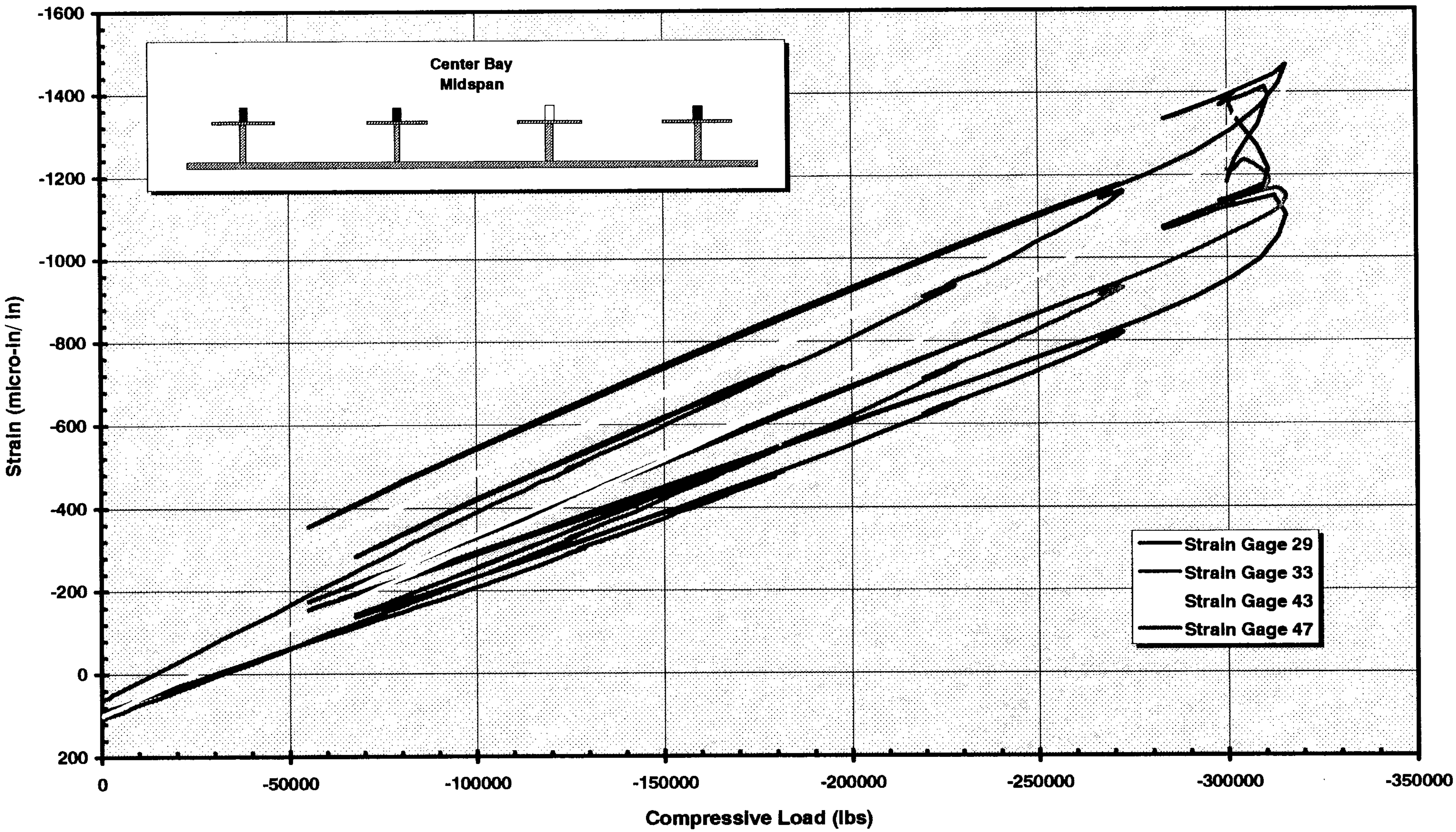
Strain vs. Applied Load



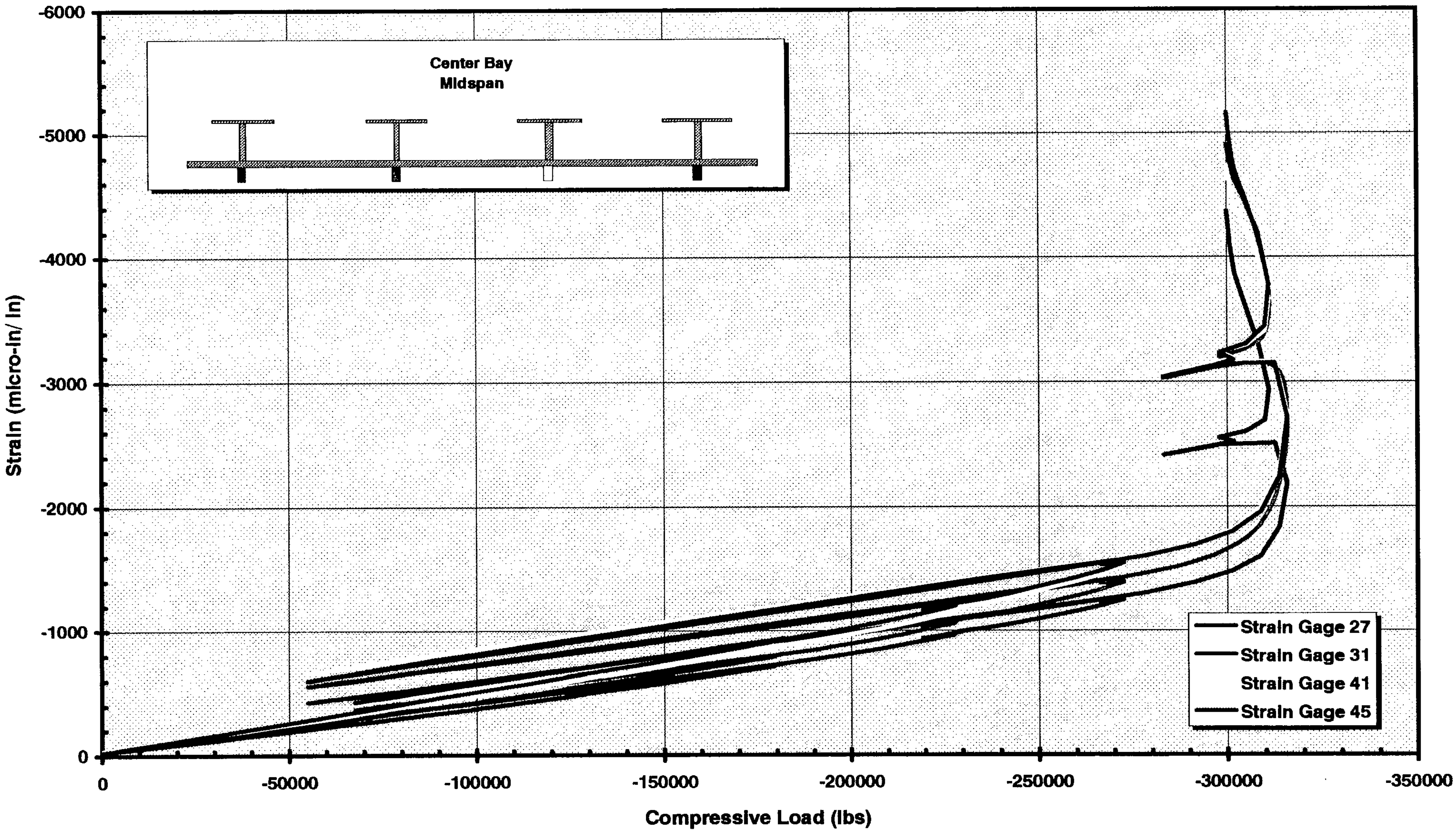
Strain vs. Applied Load



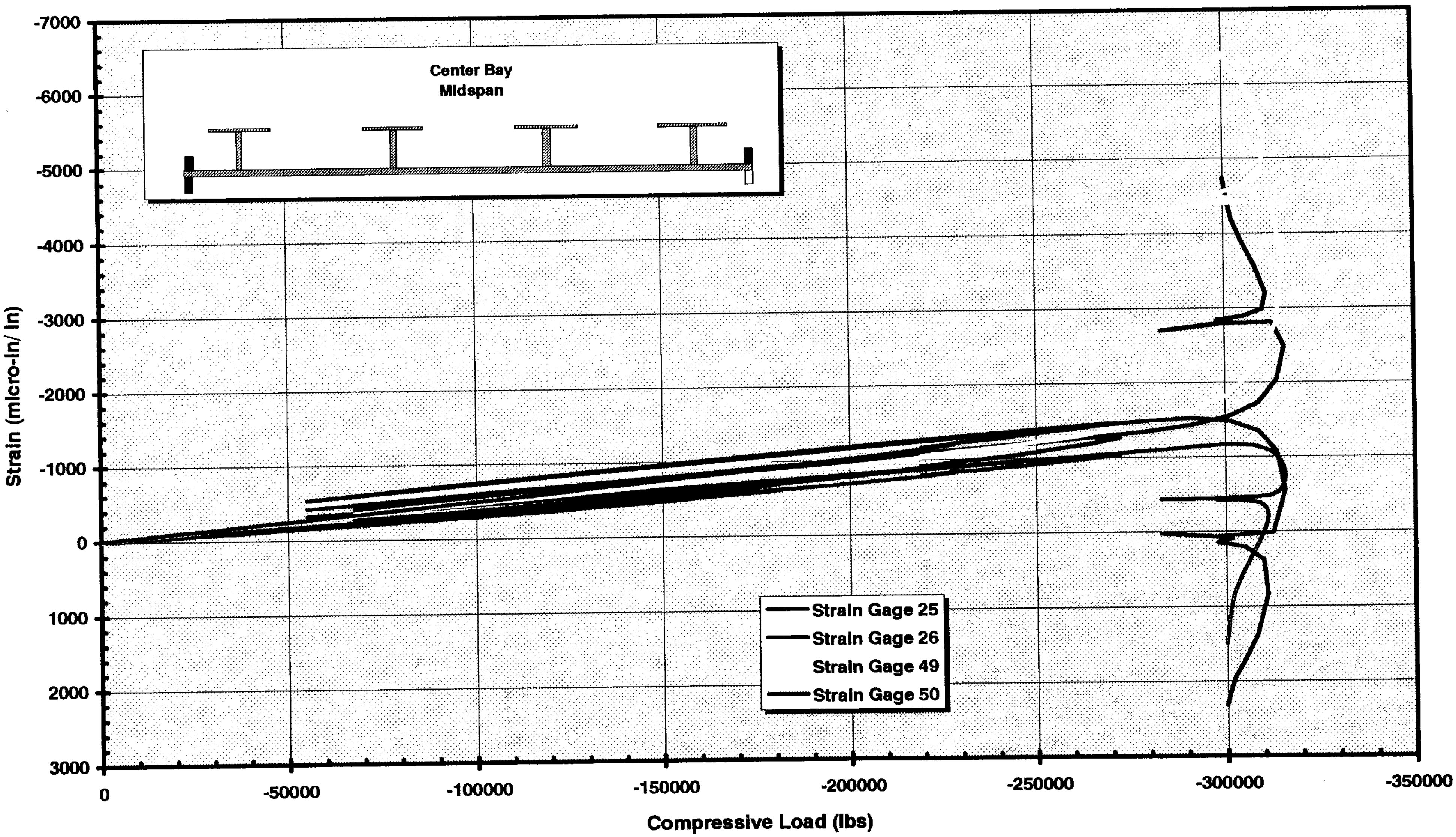
Strain vs. Applied Load



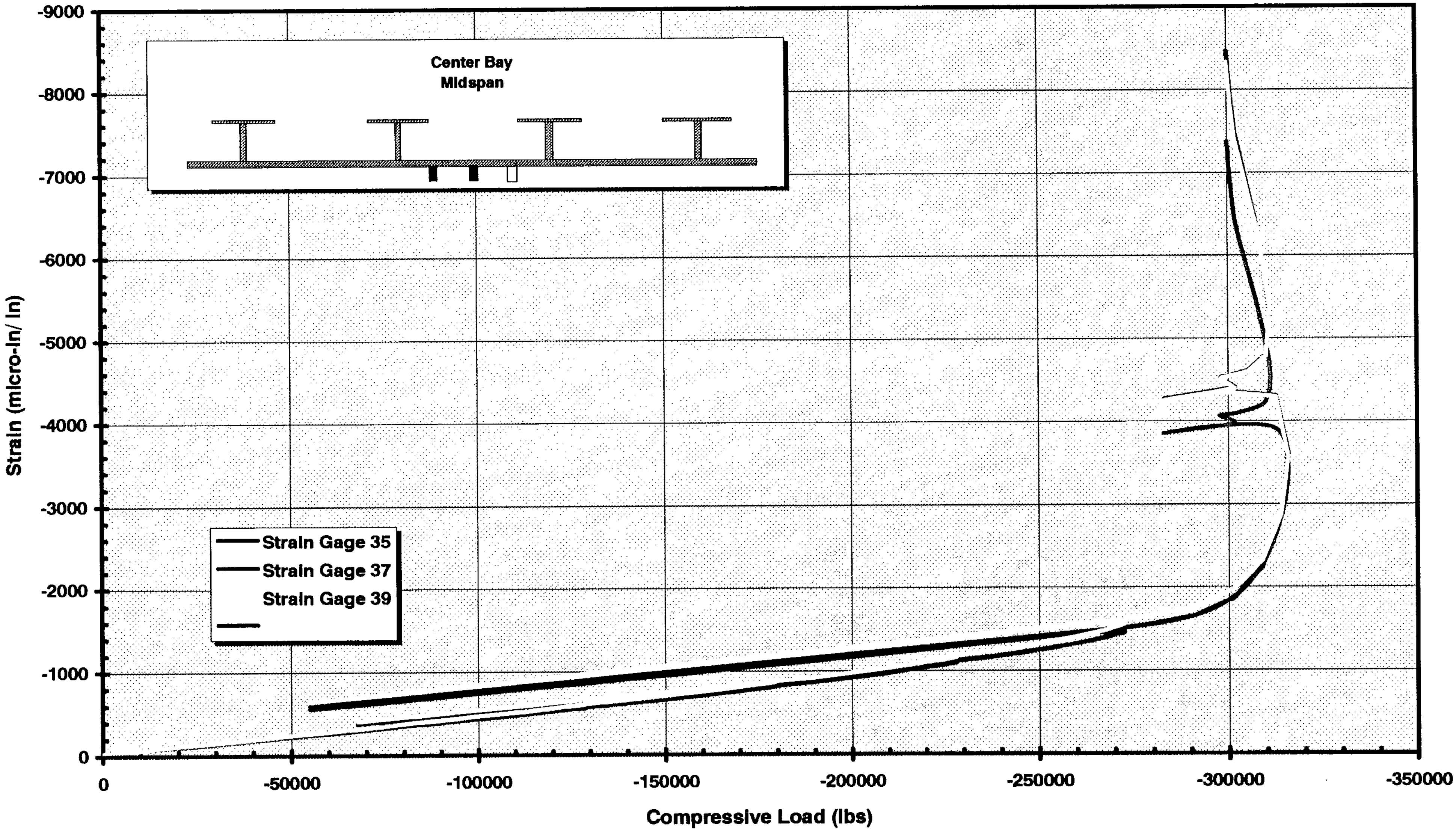
Strain vs. Applied Load



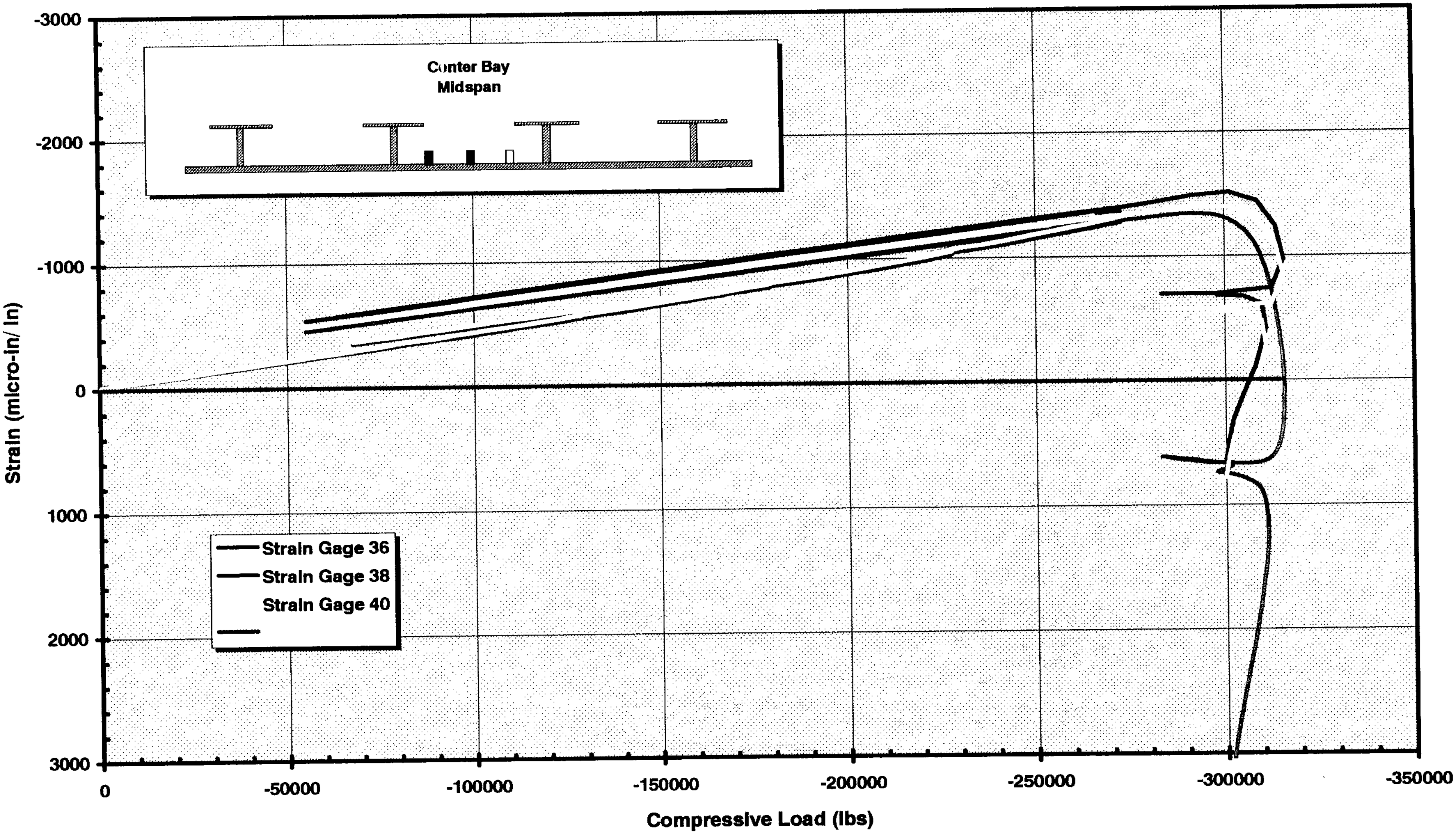
Strain vs. Applied Load

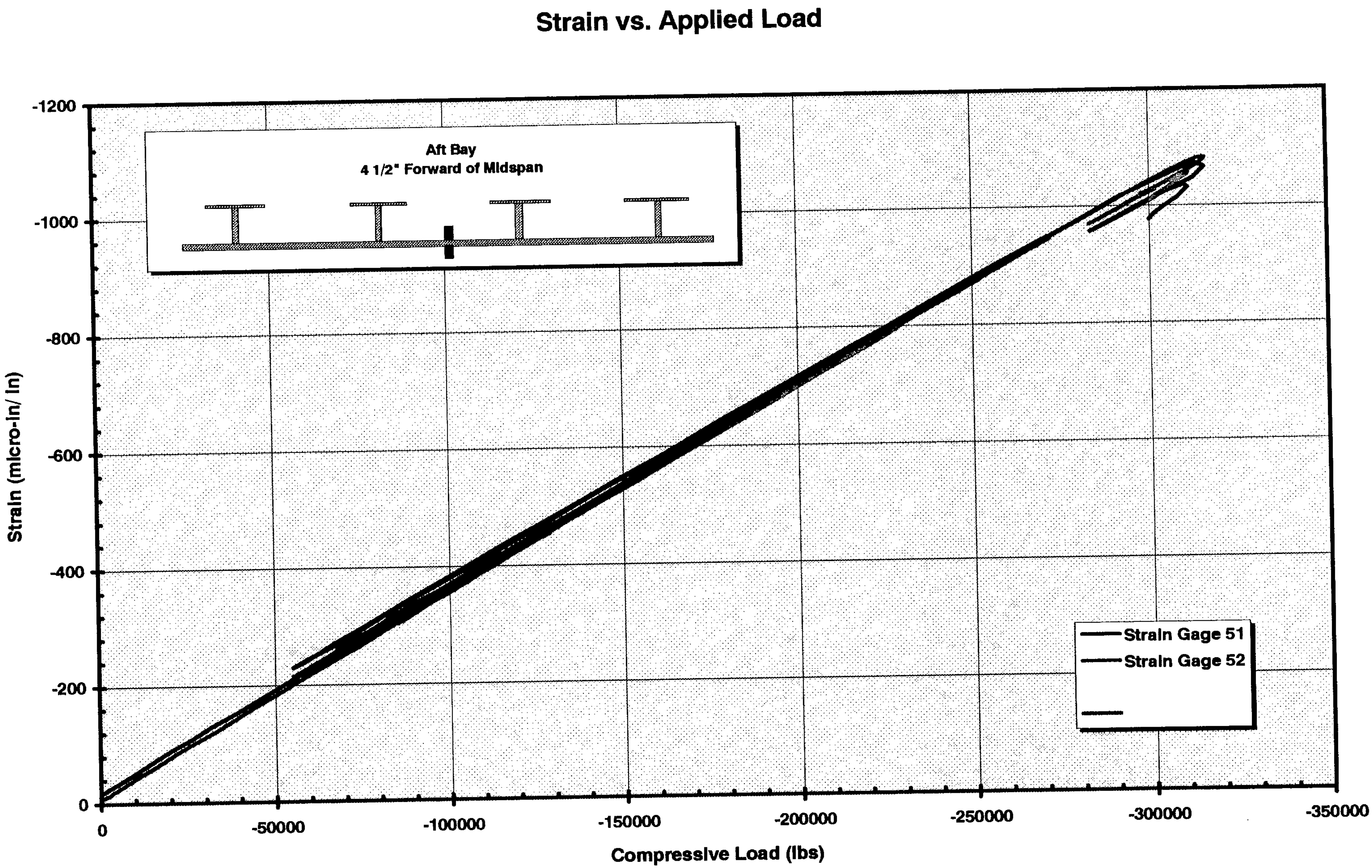


Strain vs. Applied Load



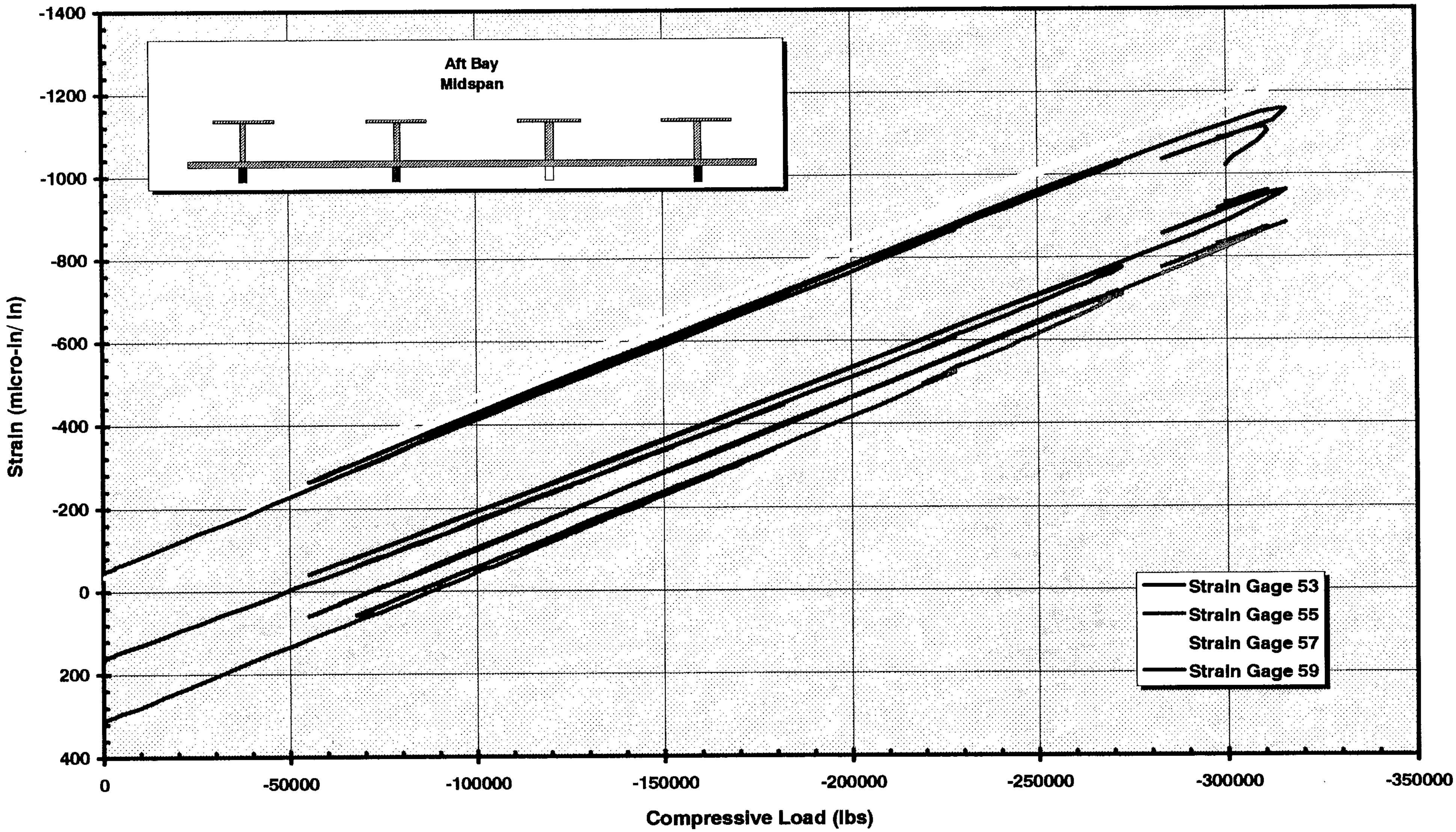
Strain vs. Applied Load



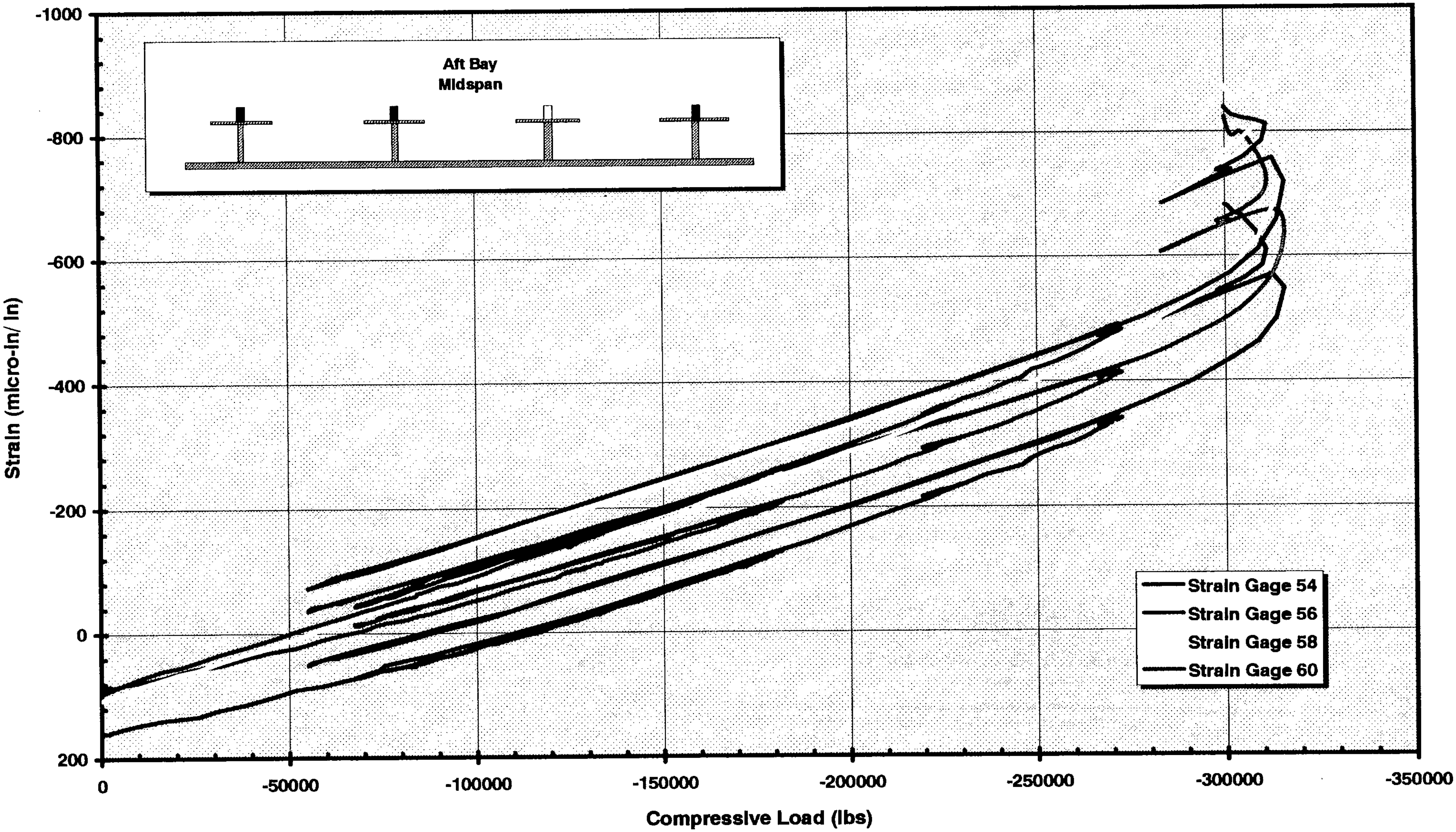


Strain vs. Applied Load
Aft Bay
4 1/2" Forward of Midspan
Strain Gage 51
Strain Gage 52
Strain (micro-in/ in)
-1200
-1000
-800
-600
-400
-200
0
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)

Strain vs. Applied Load

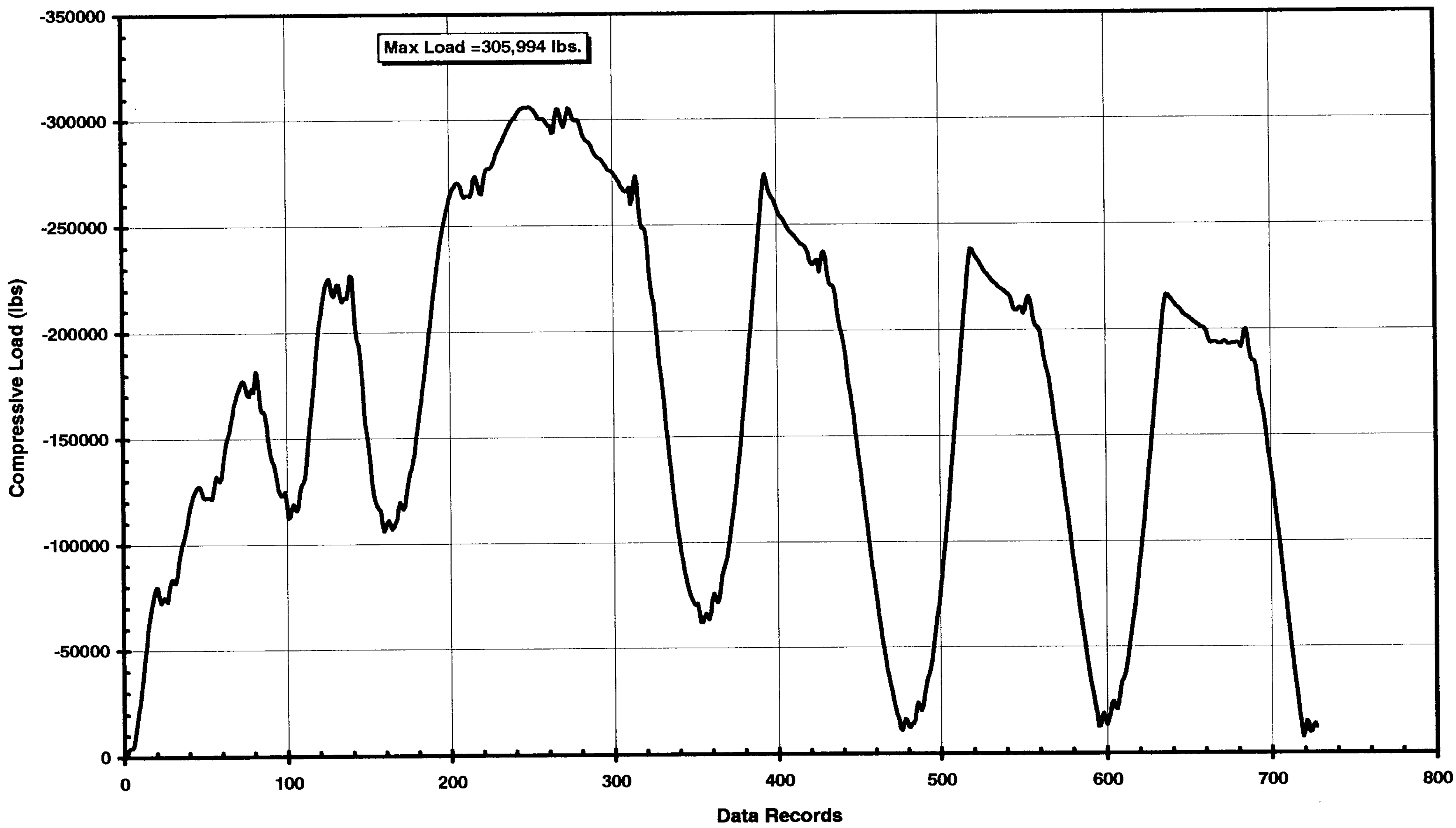


Strain vs. Applied Load

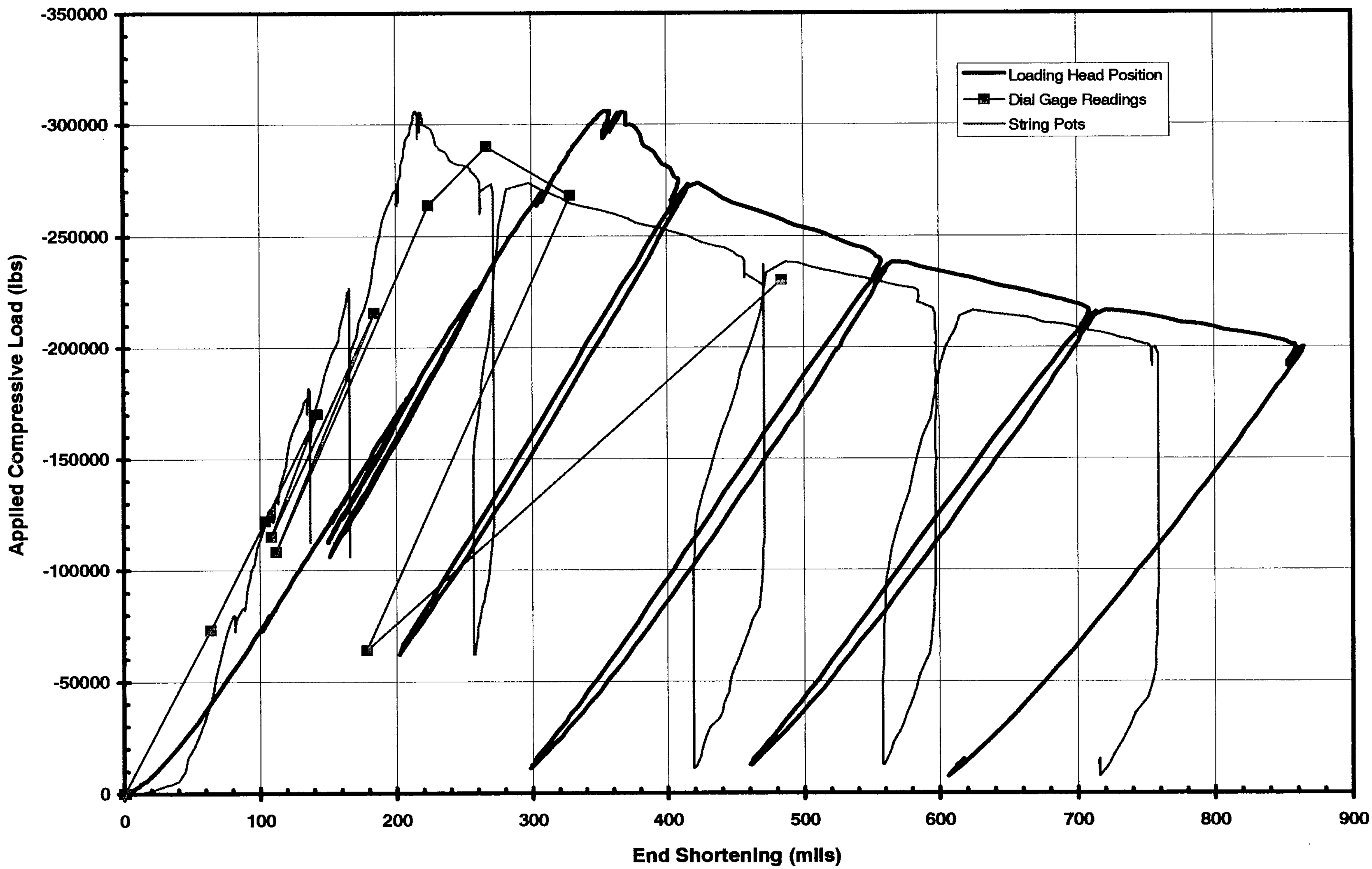


Specimen 0695 Axial and Lateral Load

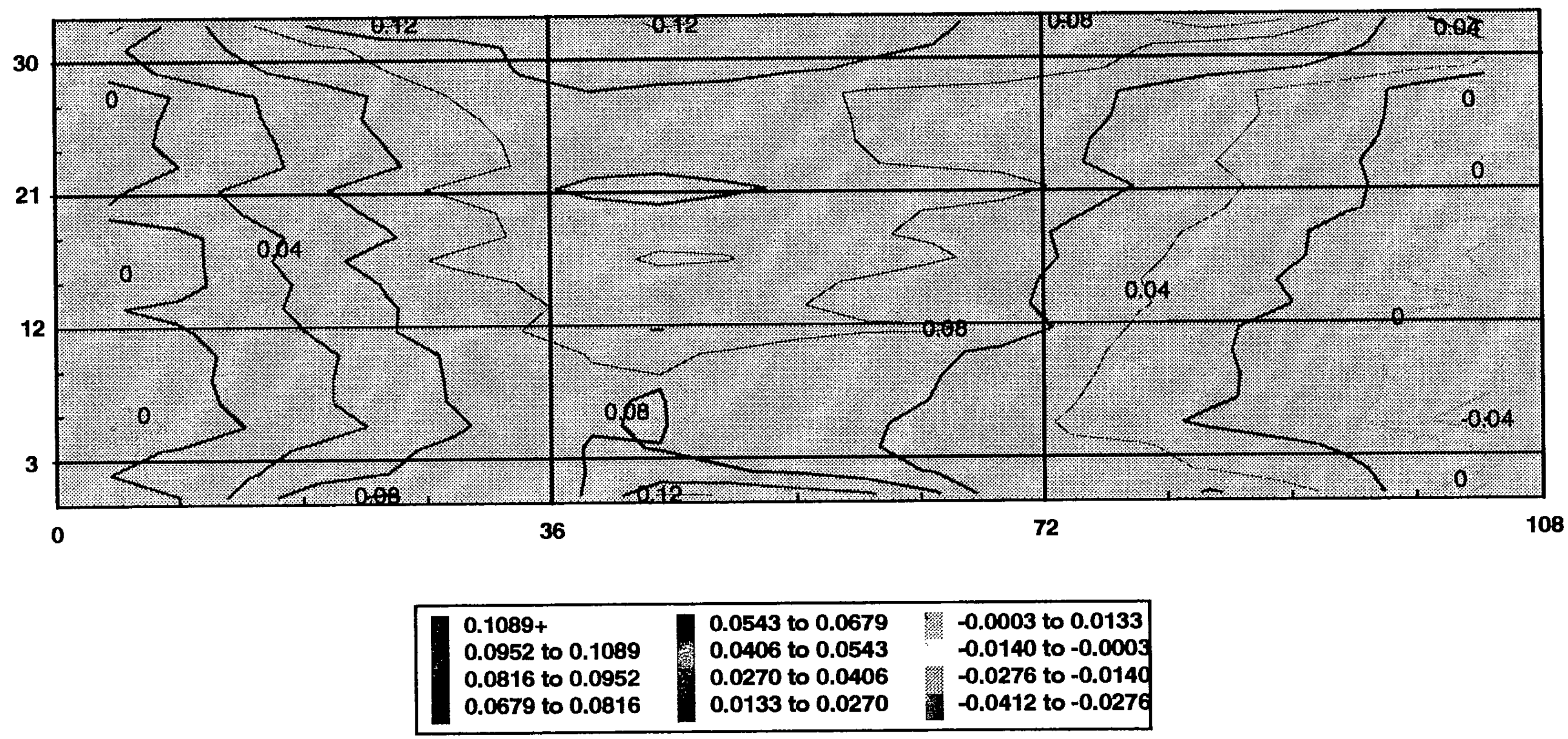
Load History



Load vs. End Shortening

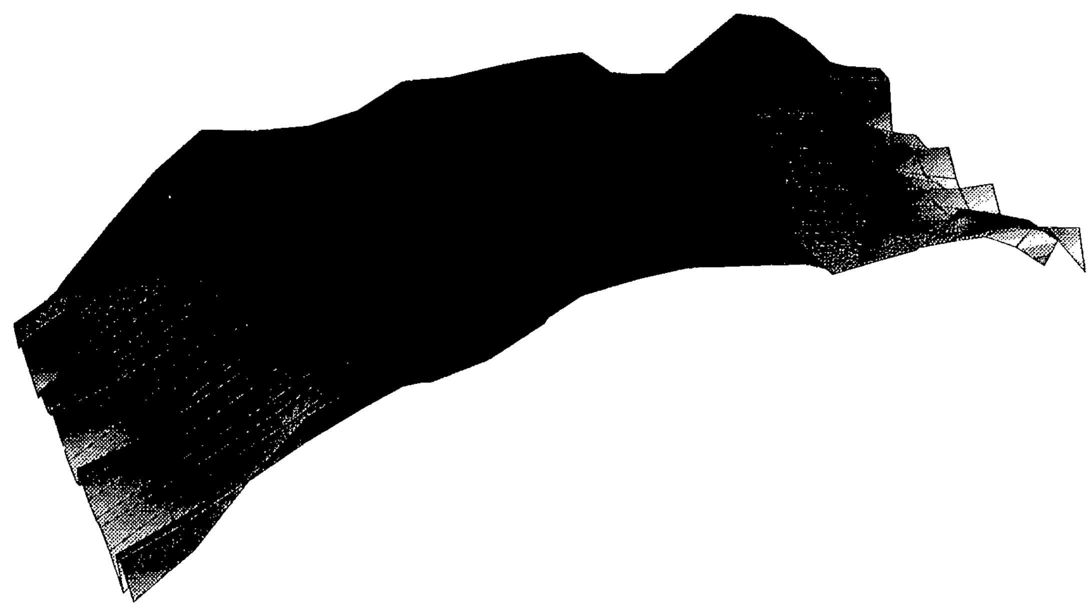


Pre-Test Survey

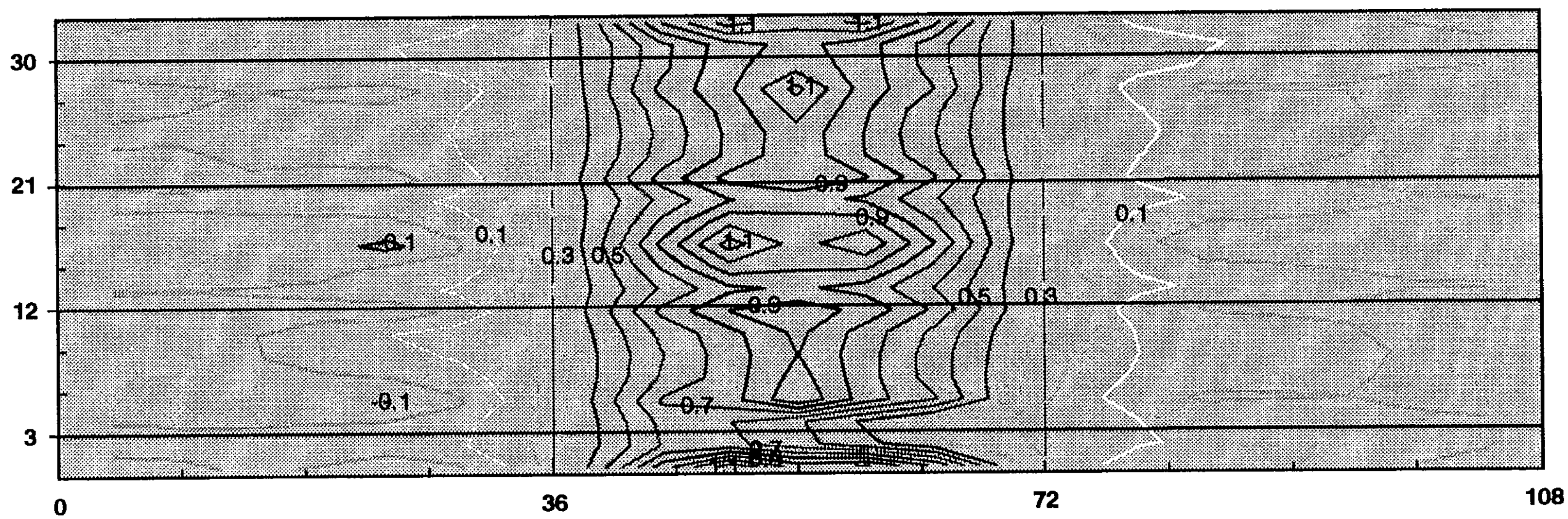


All measurements are in inches

Pre-Test Survey



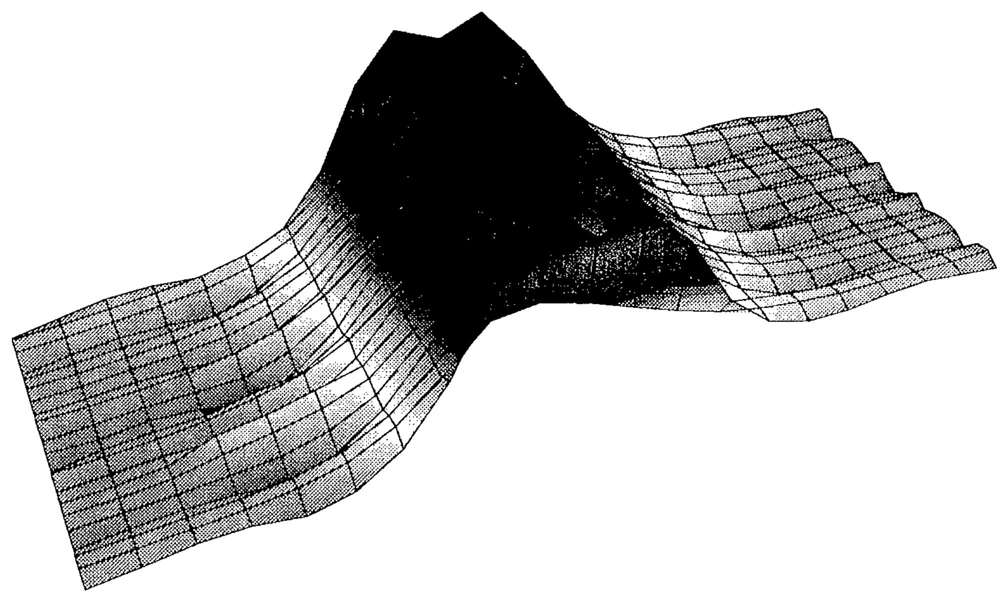
Post-Test Survey



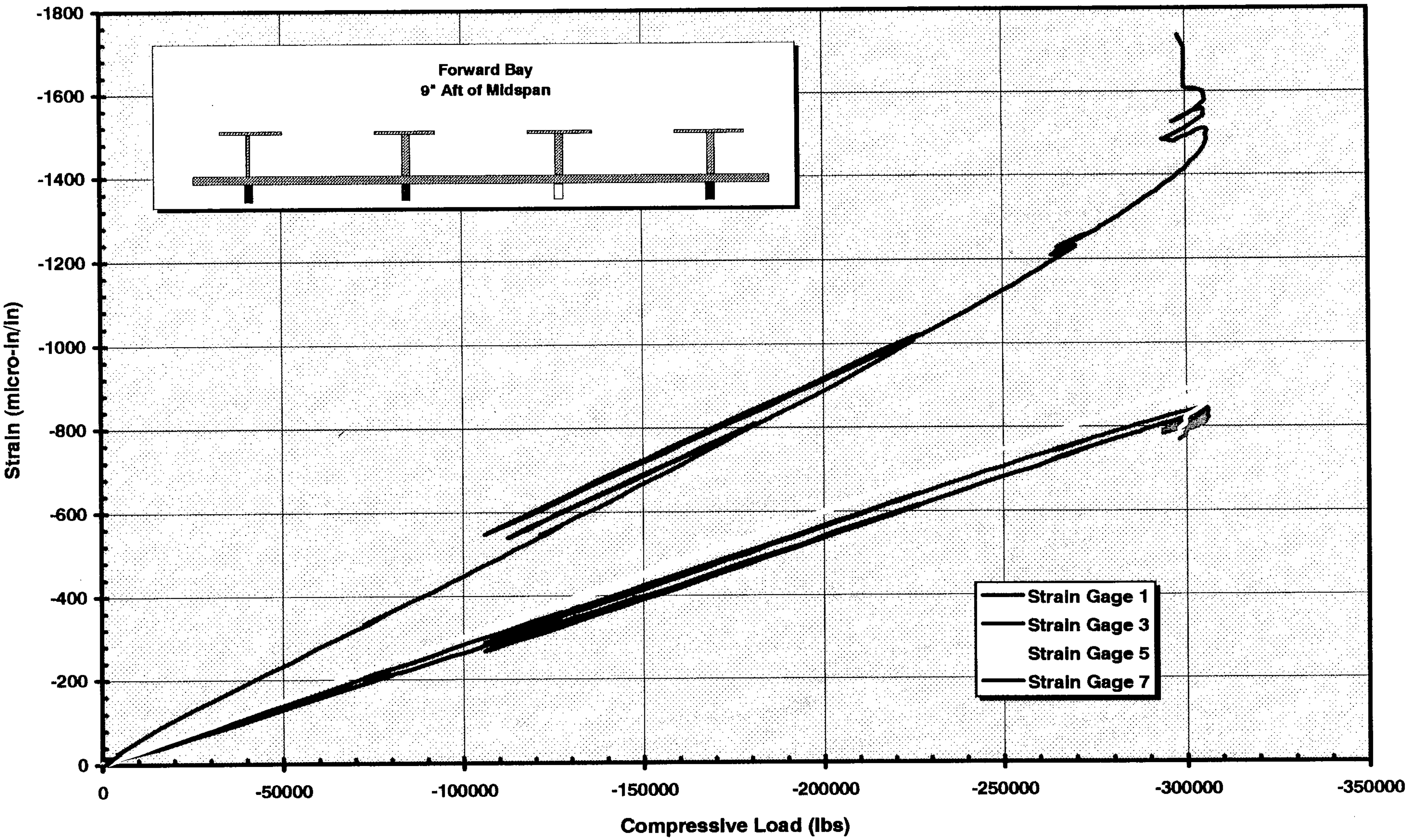
1.0610+	0.1966 to 0.3047
0.9529 to 1.0610	0.0886 to 0.1966
0.8449 to 0.9529	-0.0195 to 0.0886
0.7368 to 0.8449	-0.1275 to -0.0195
0.6288 to 0.7368	
0.5208 to 0.6288	
0.4127 to 0.5208	
0.3047 to 0.4127	

All measurements are in inches

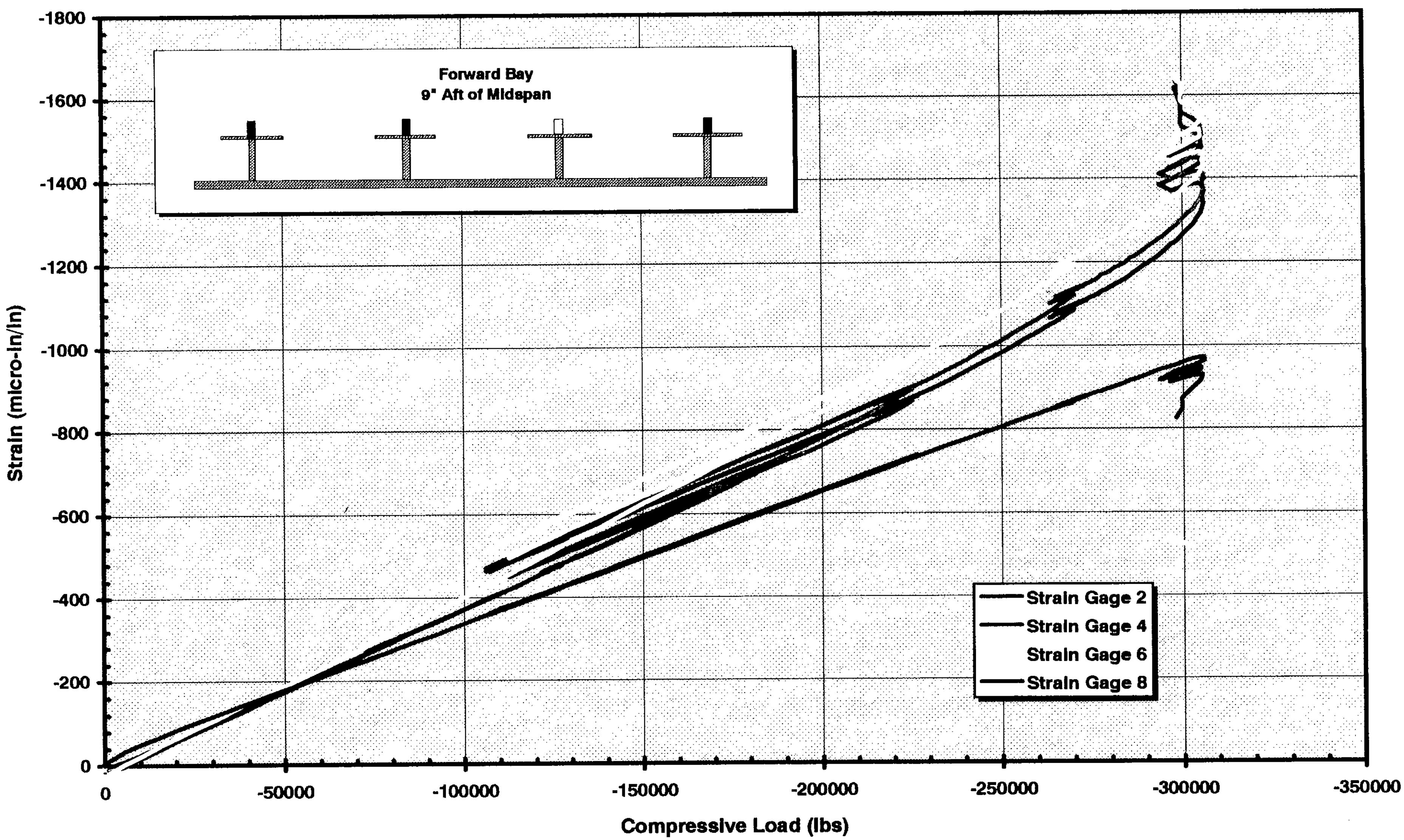
Post-Test Survey



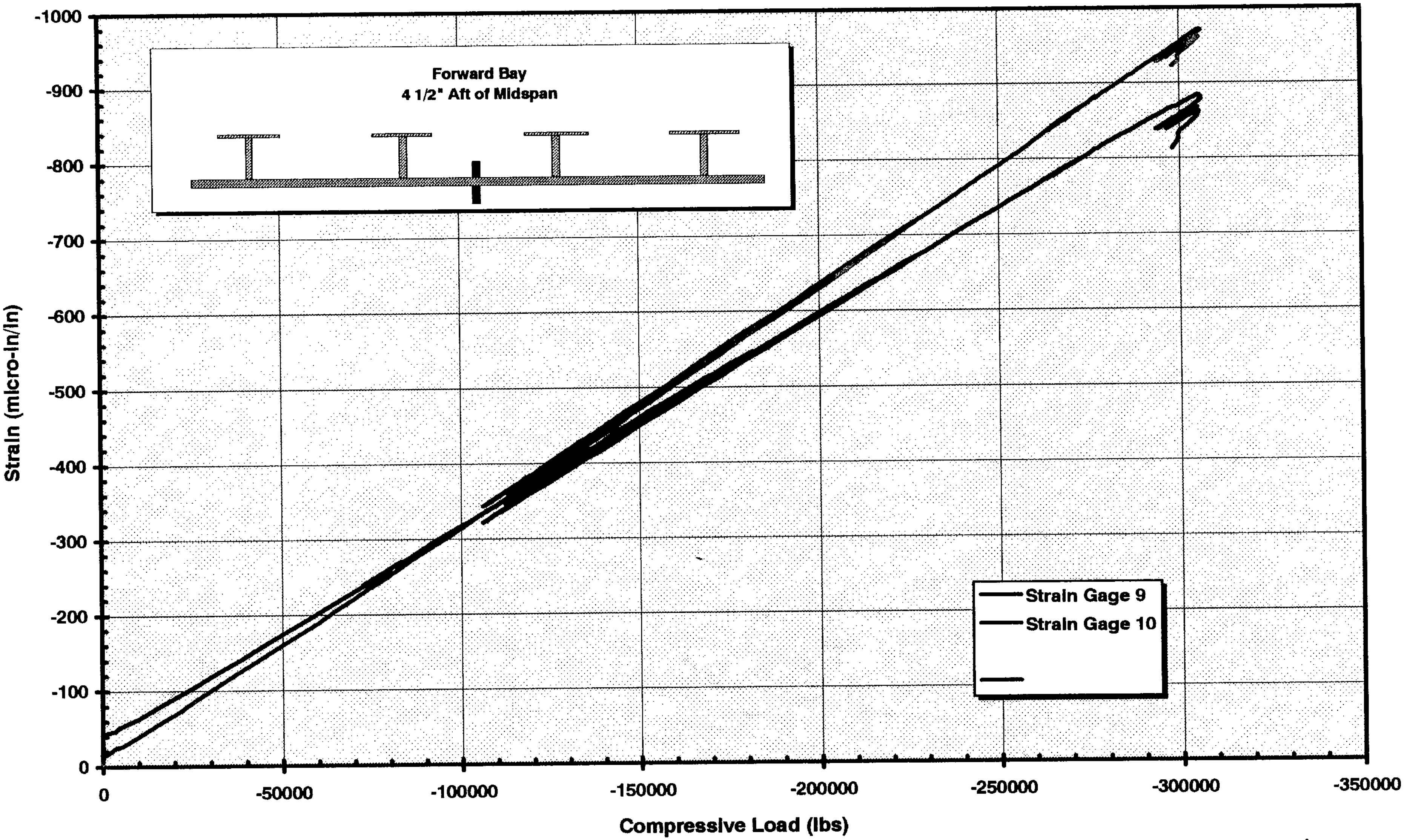
Strain vs. Applied Load



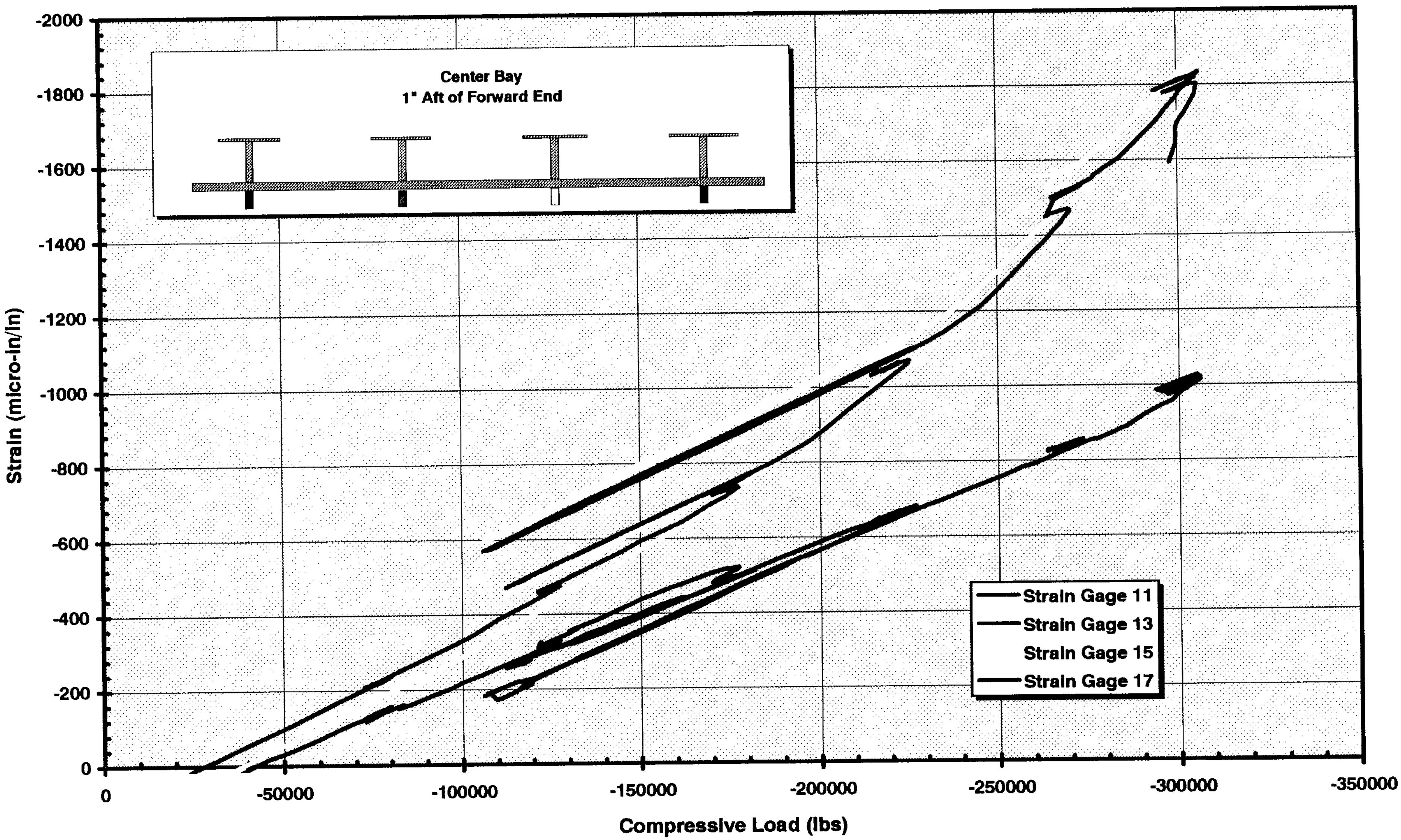
Strain vs. Applied Load



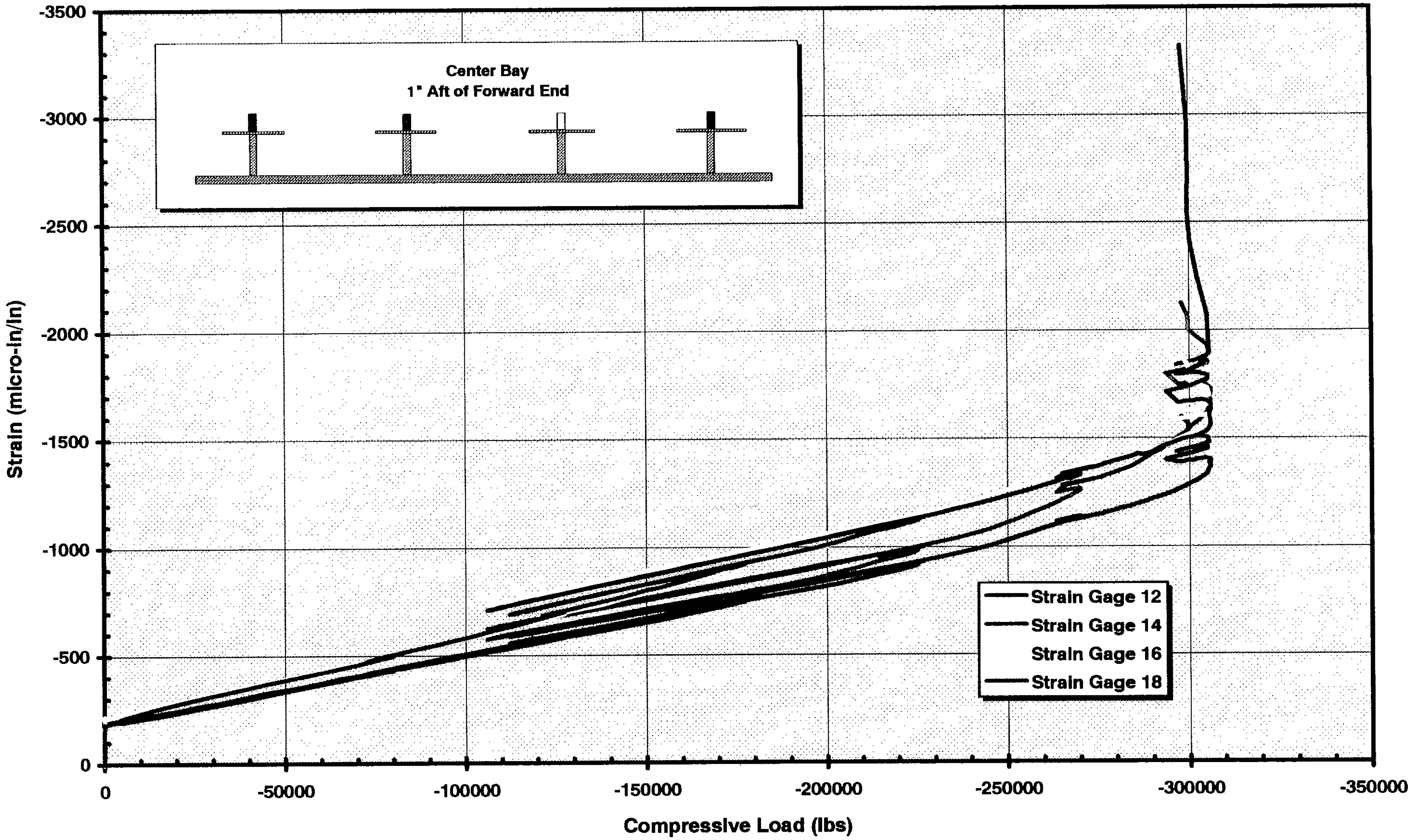
Strain vs. Applied Load



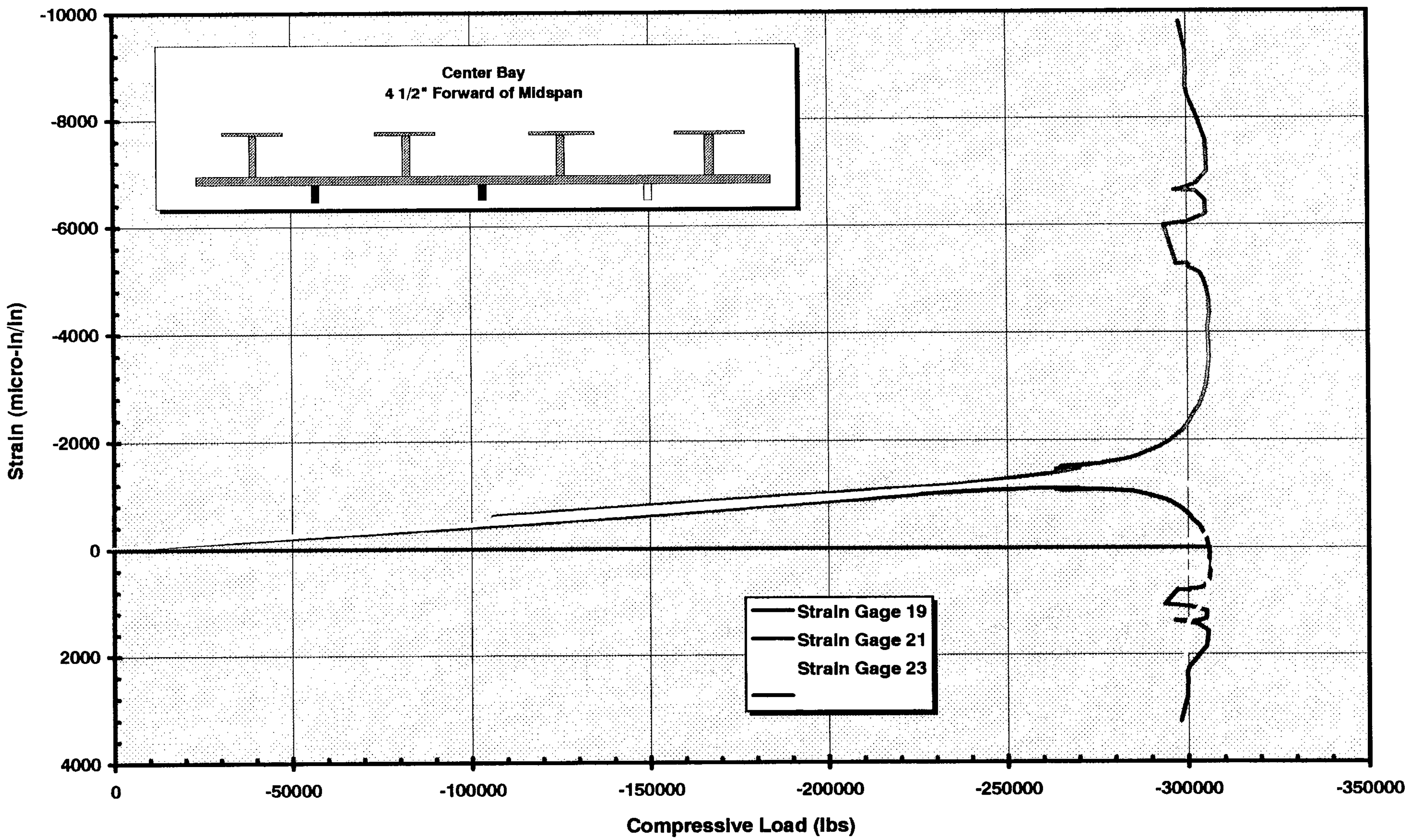
Strain vs. Applied Load



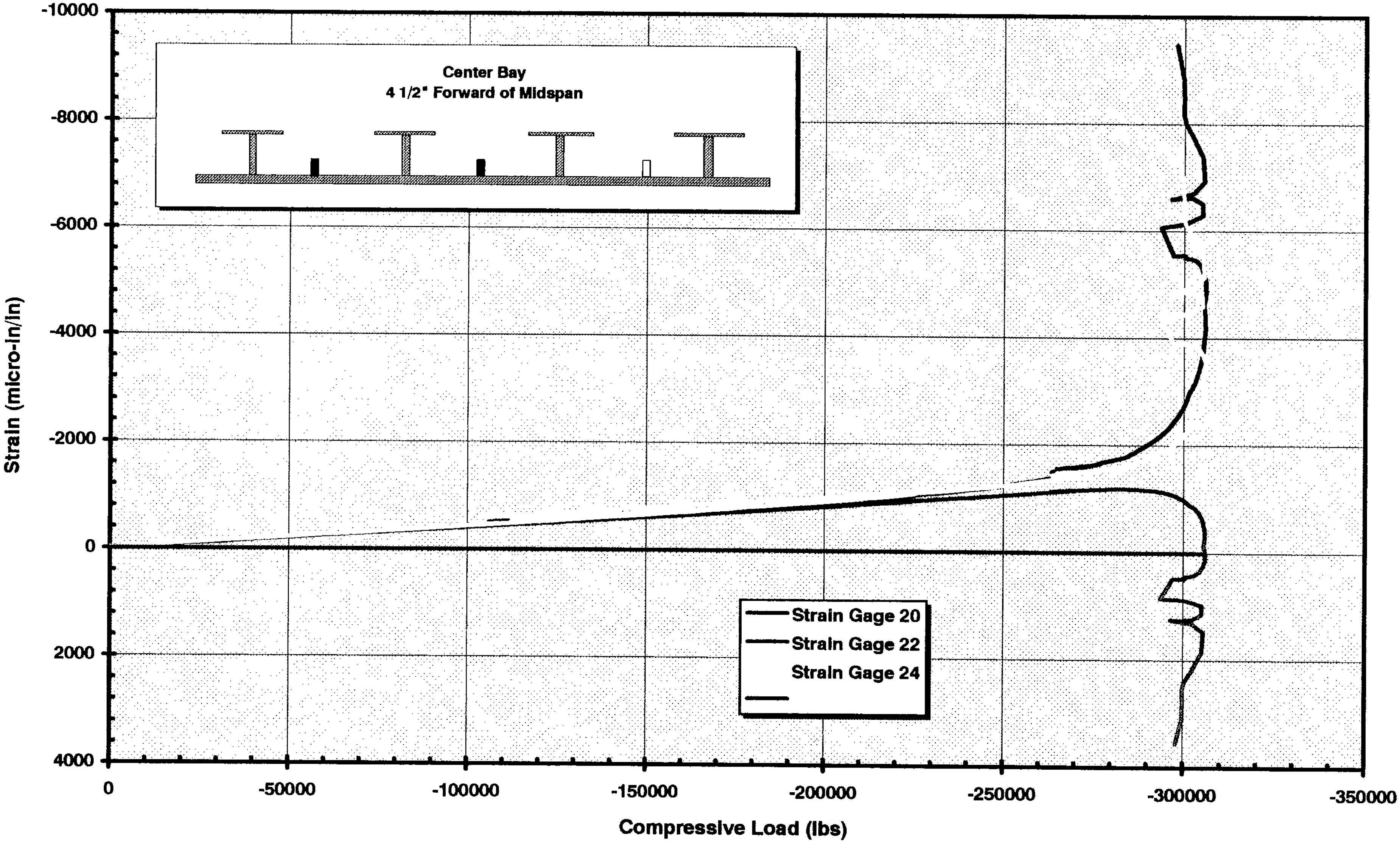
Strain vs. Applied Load



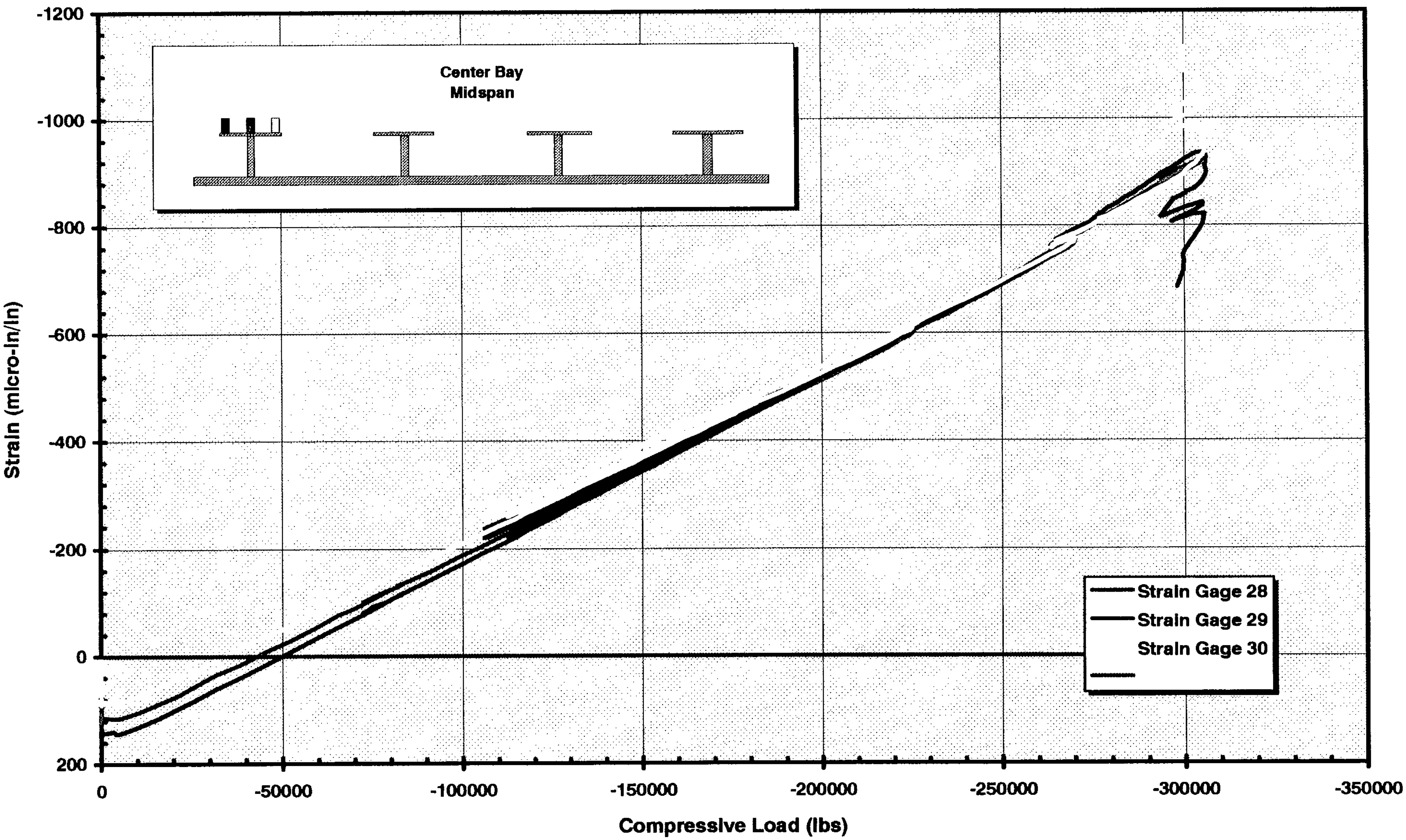
Strain vs. Applied Load



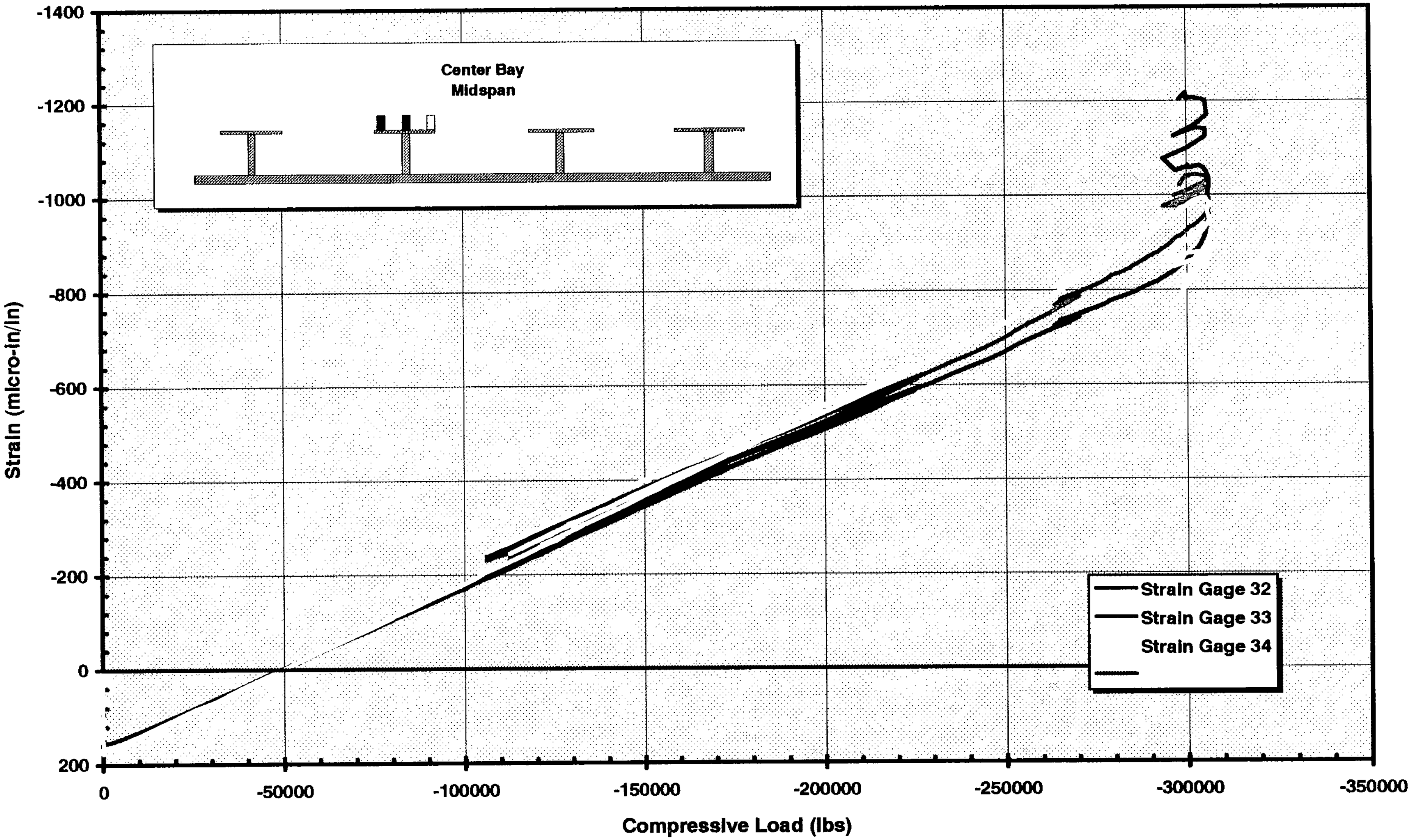
Strain vs. Applied Load



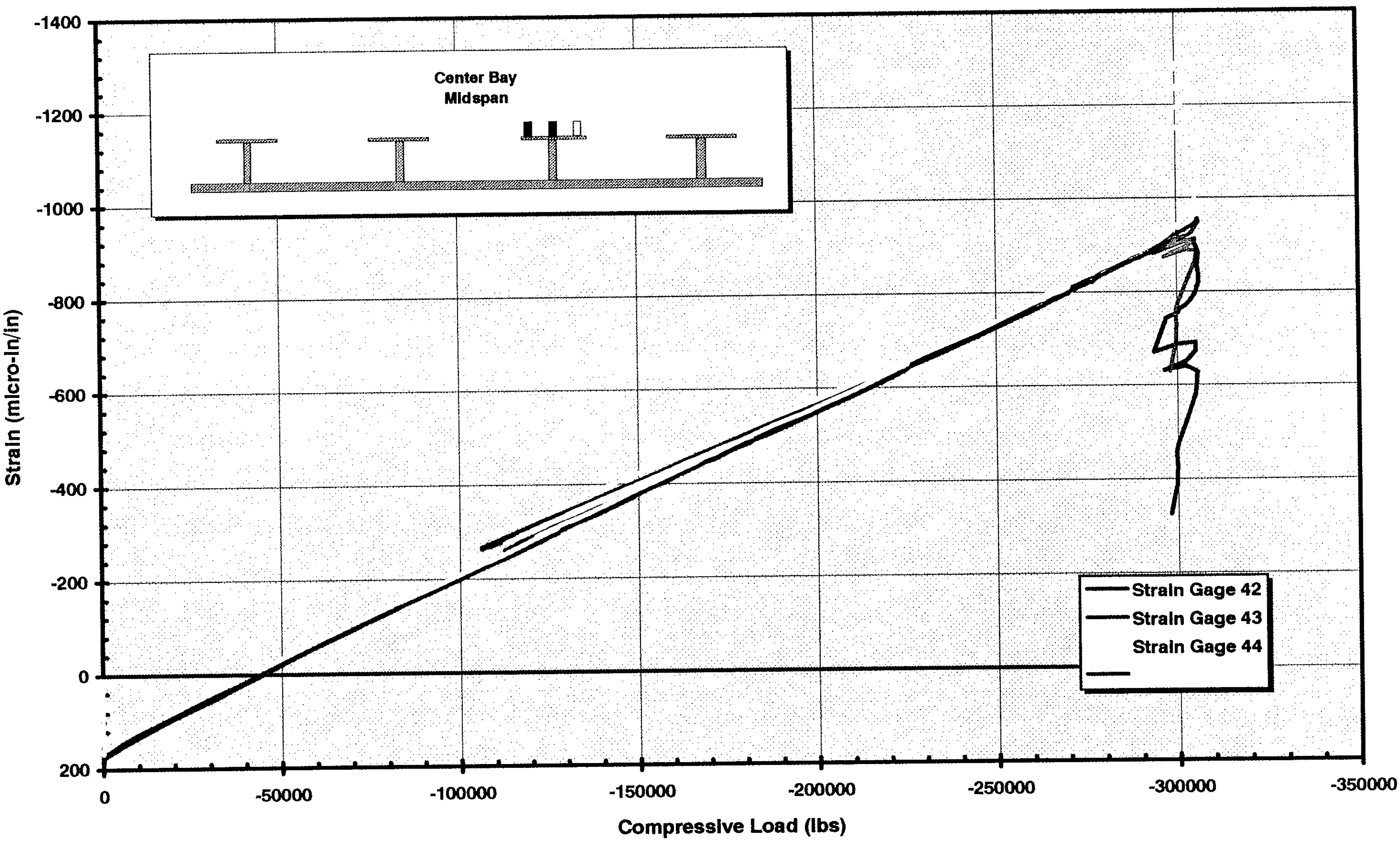
Strain vs. Applied Load



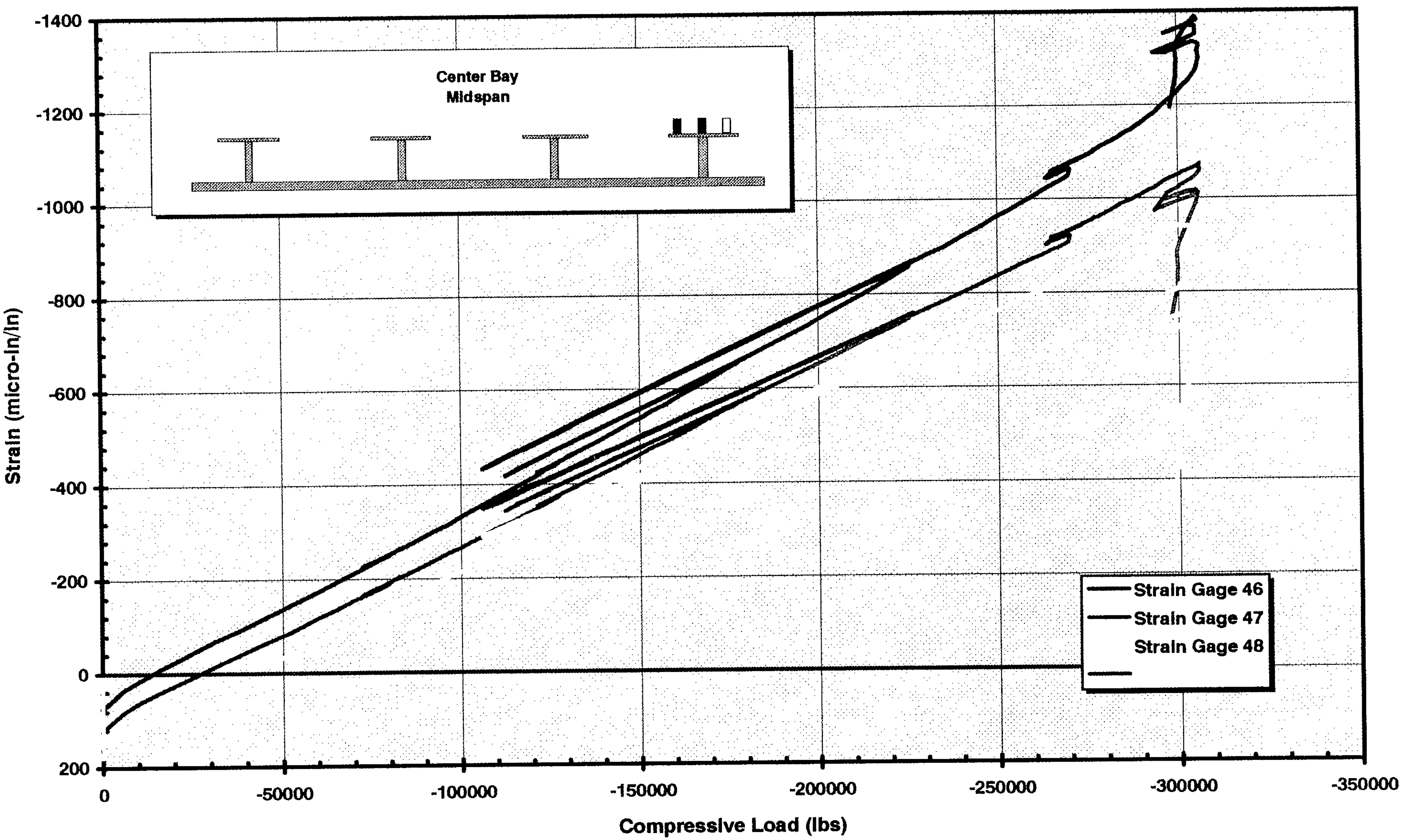
Strain vs. Applied Load



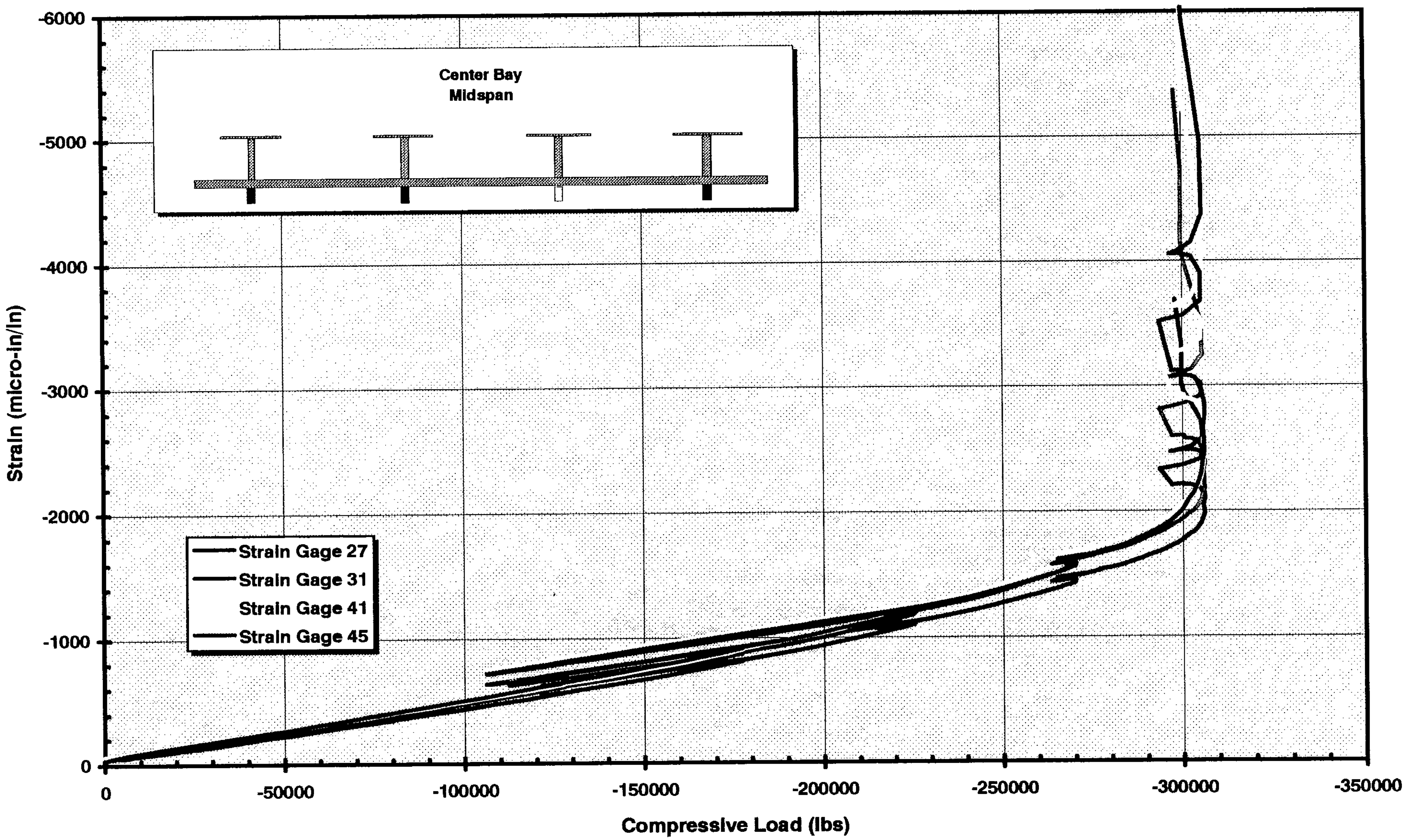
Strain vs. Applied Load



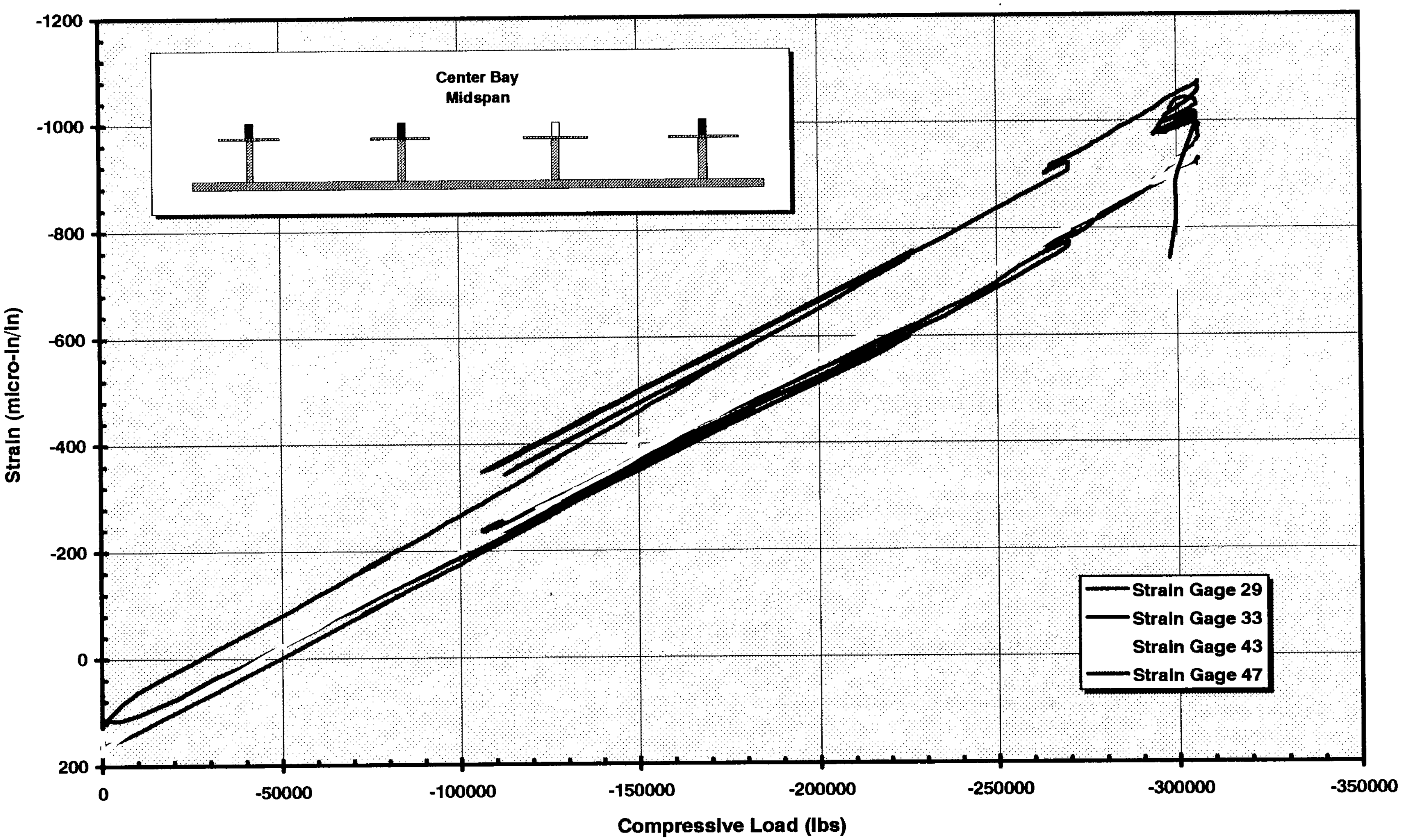
Strain vs. Applied Load



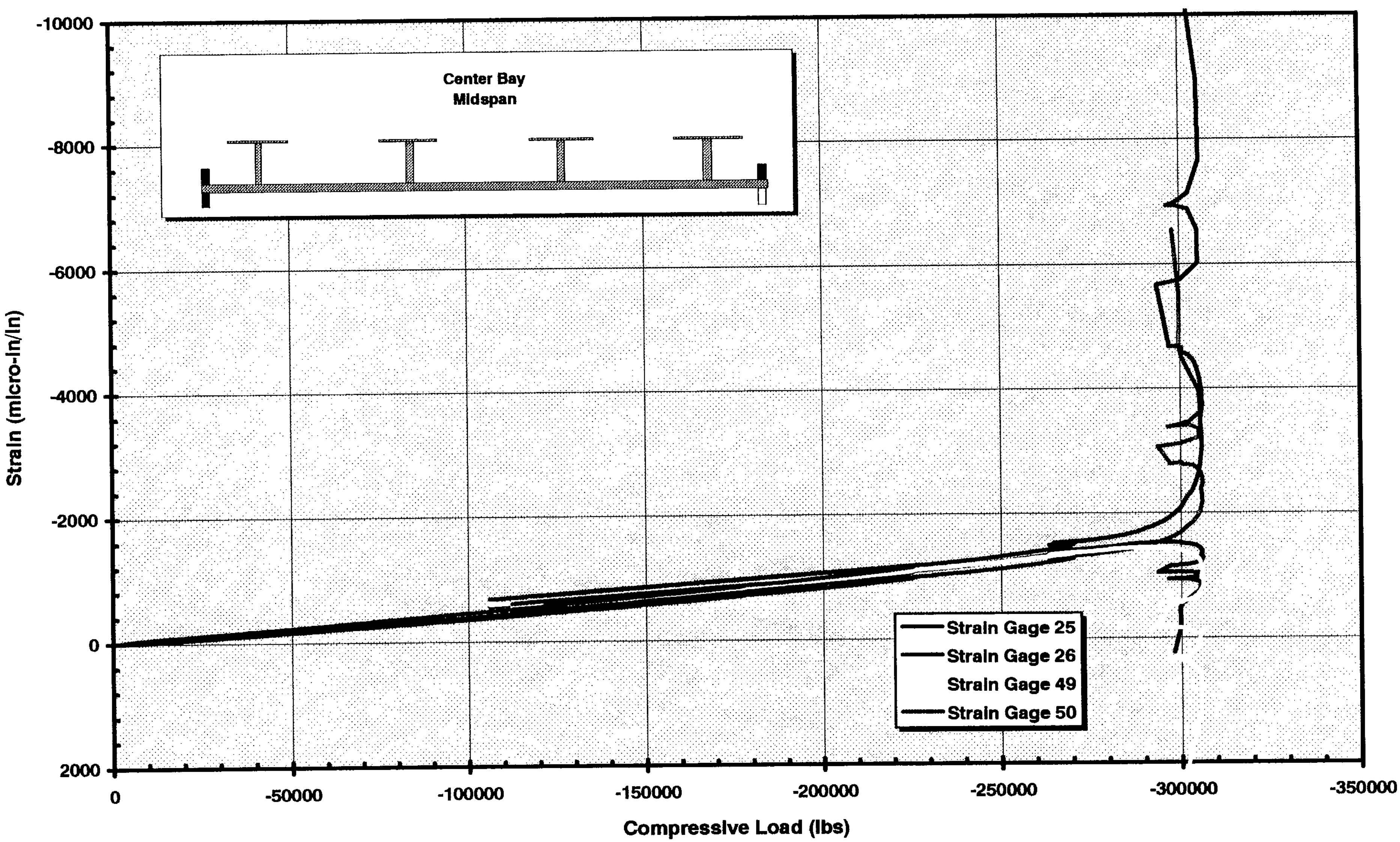
Strain vs. Applied Load

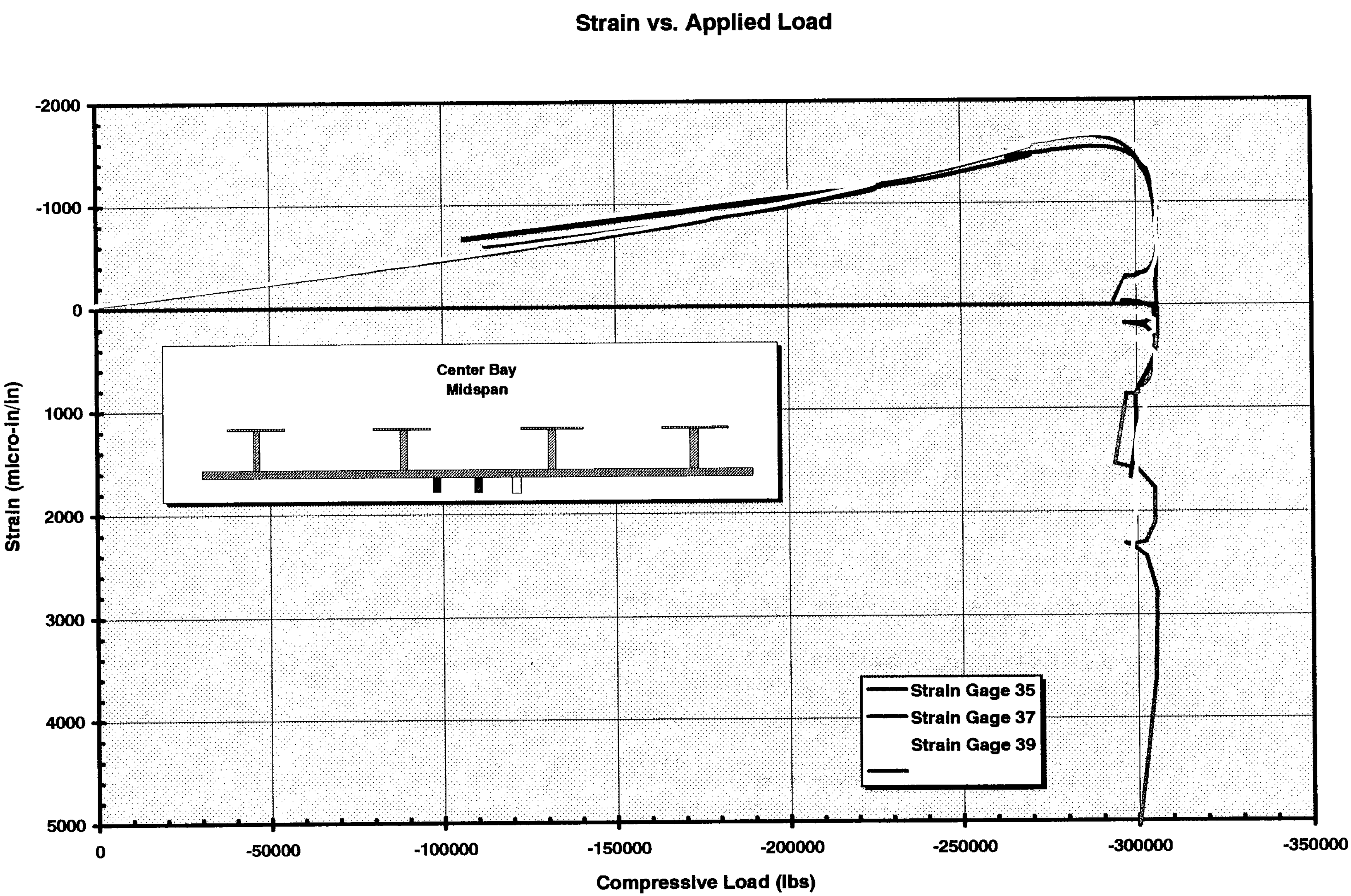


Strain vs. Applied Load

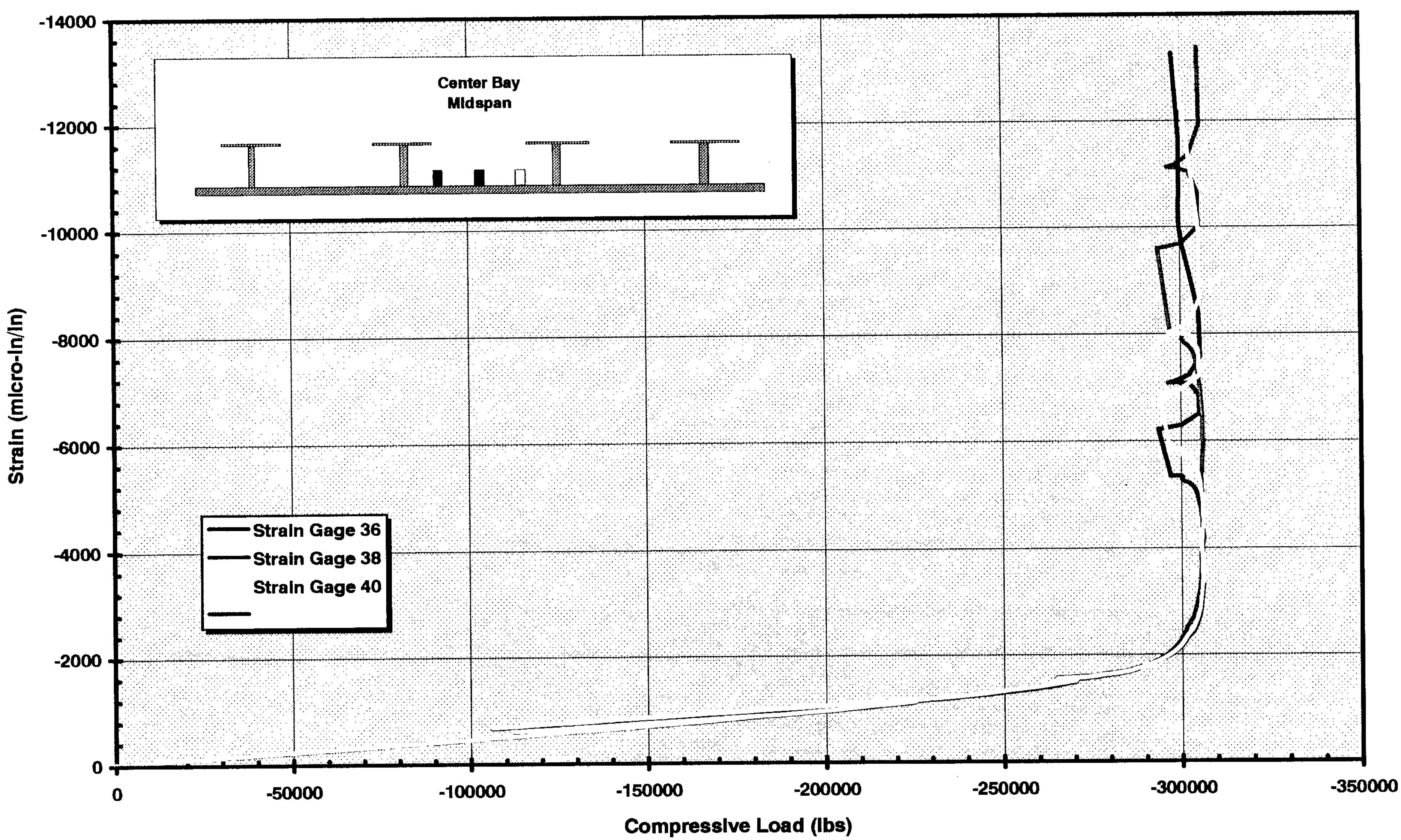


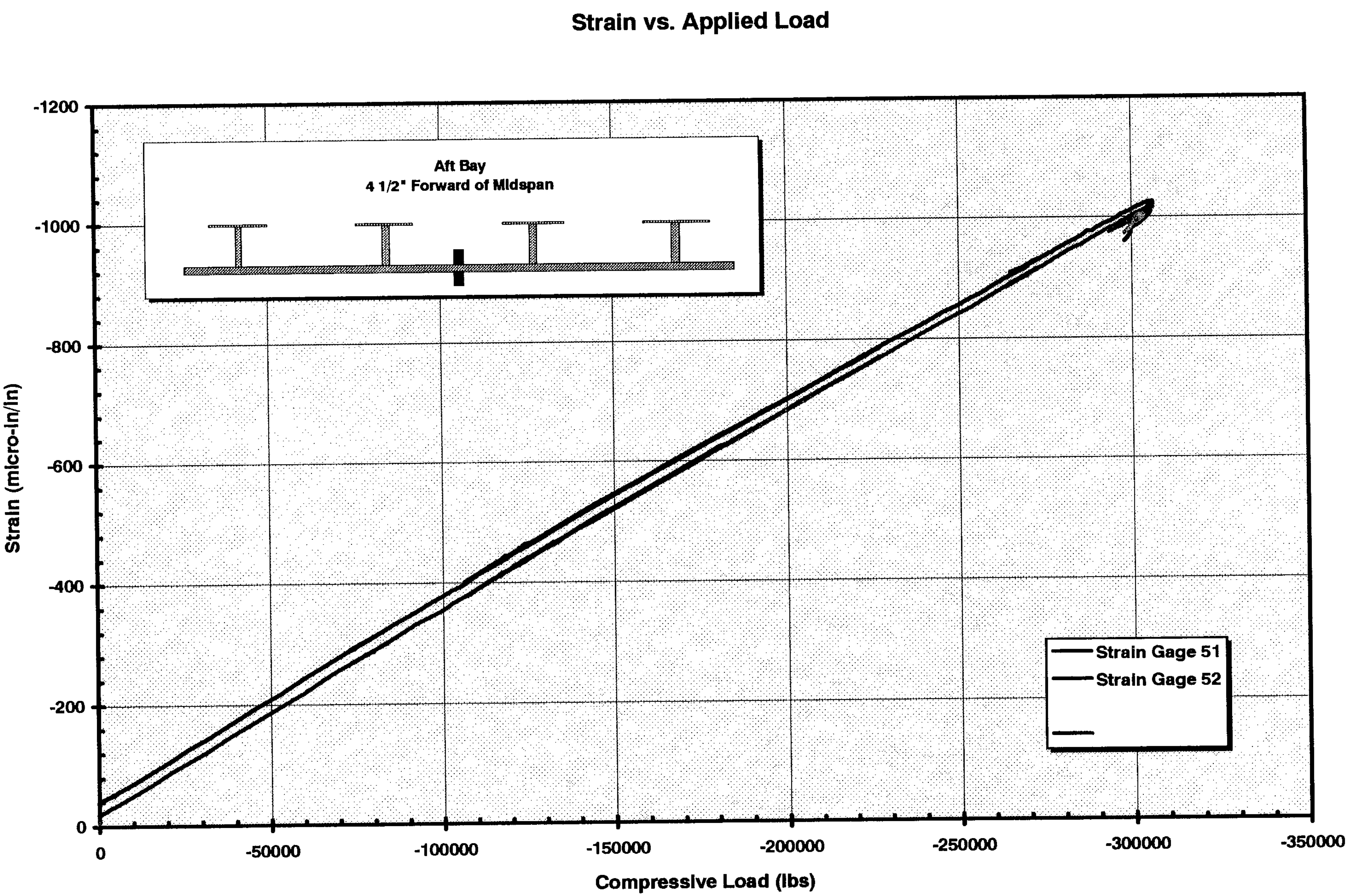
Strain vs. Applied Load

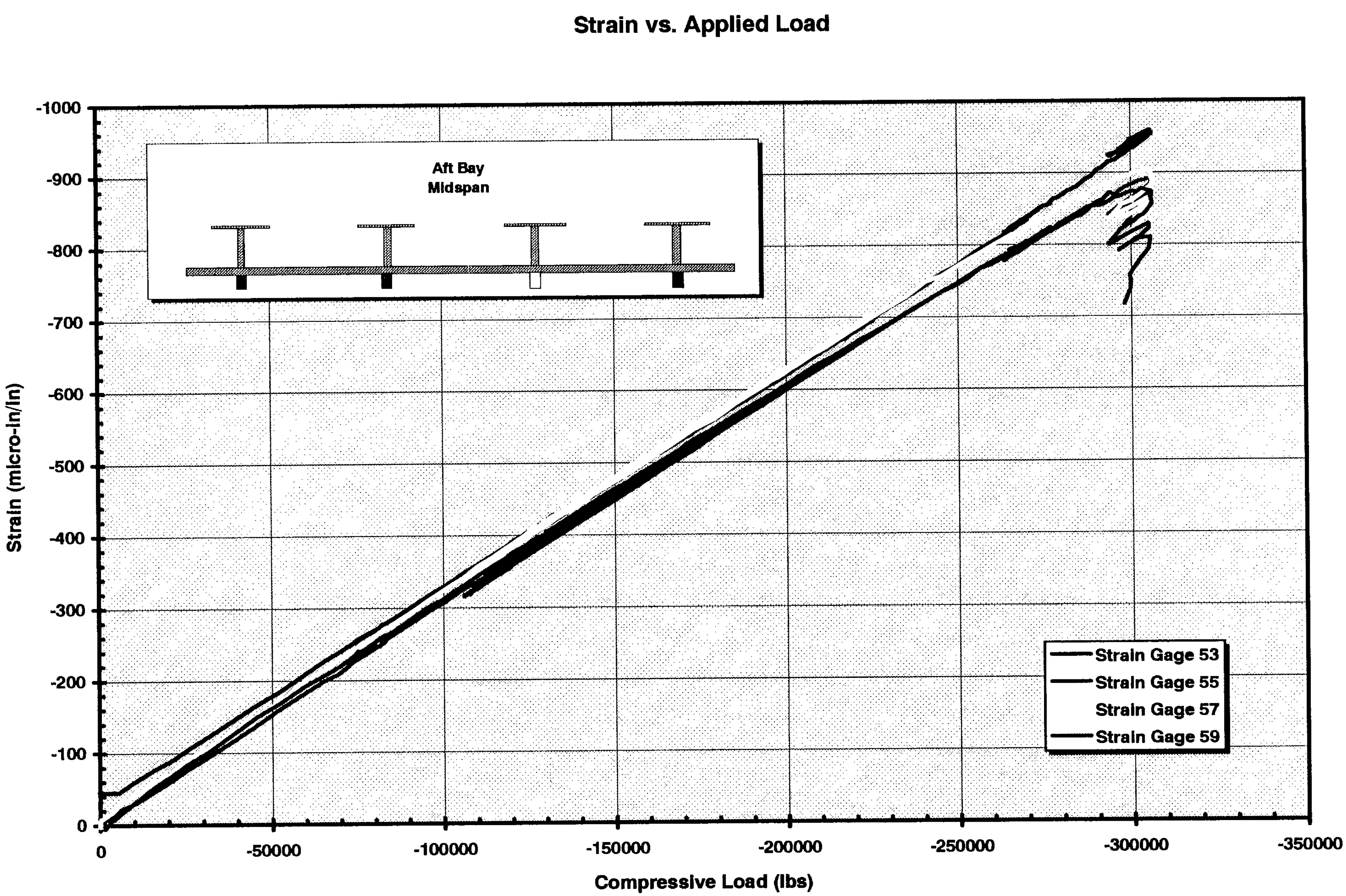



Strain vs. Applied Load
Strain (micro-in/in)
-2000
-1000
0
1000
2000
3000
4000
5000
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)
Center Bay
Midspan
Strain Gage 35
Strain Gage 37
Strain Gage 39

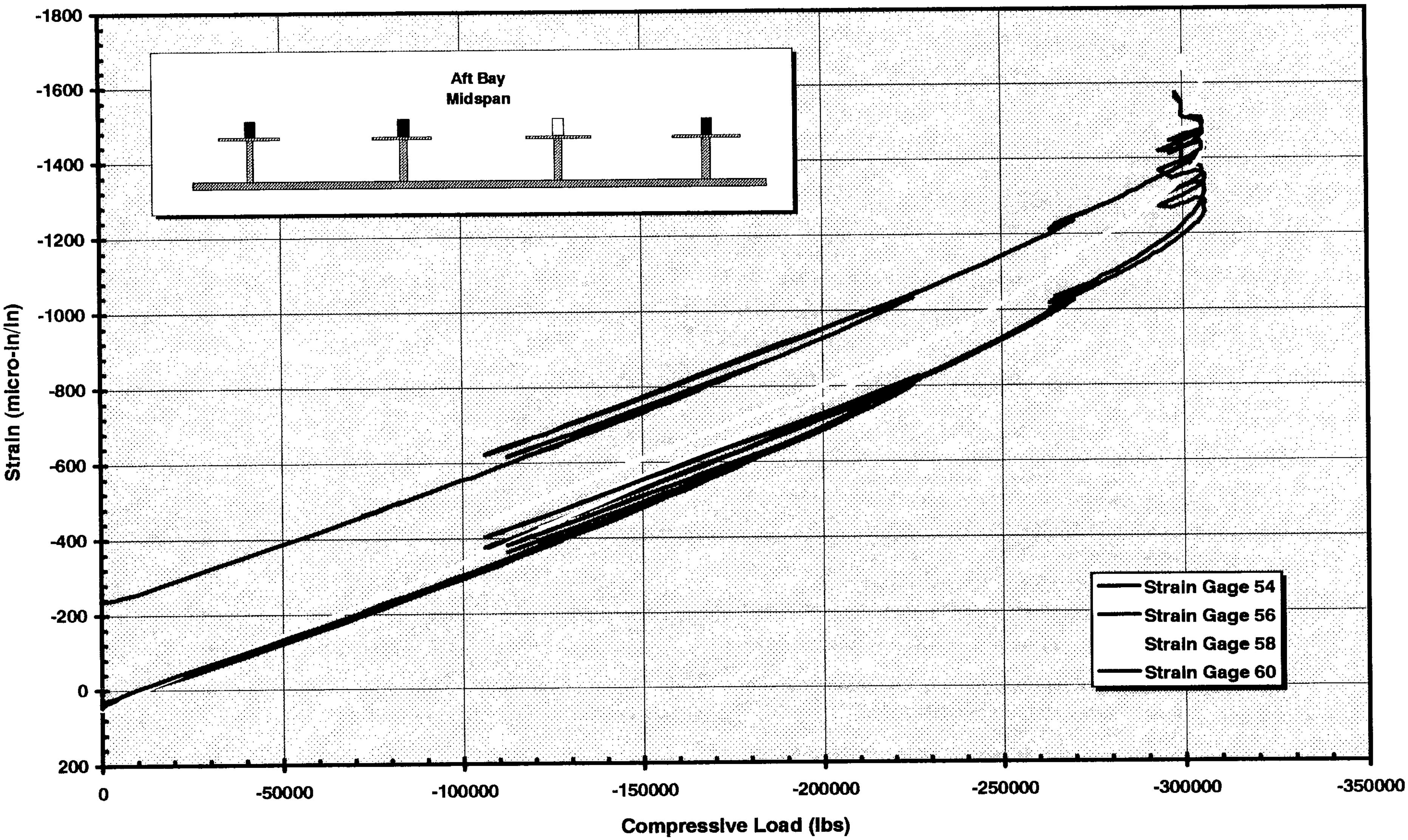
Strain vs. Applied Load




Strain vs. Applied Load
Aft Bay
4 1/2" Forward of Midspan
Strain Gage 51
Strain Gage 52
-1200
-1000
-800
-600
-400
-200
0
Strain (micro-in/in)
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)

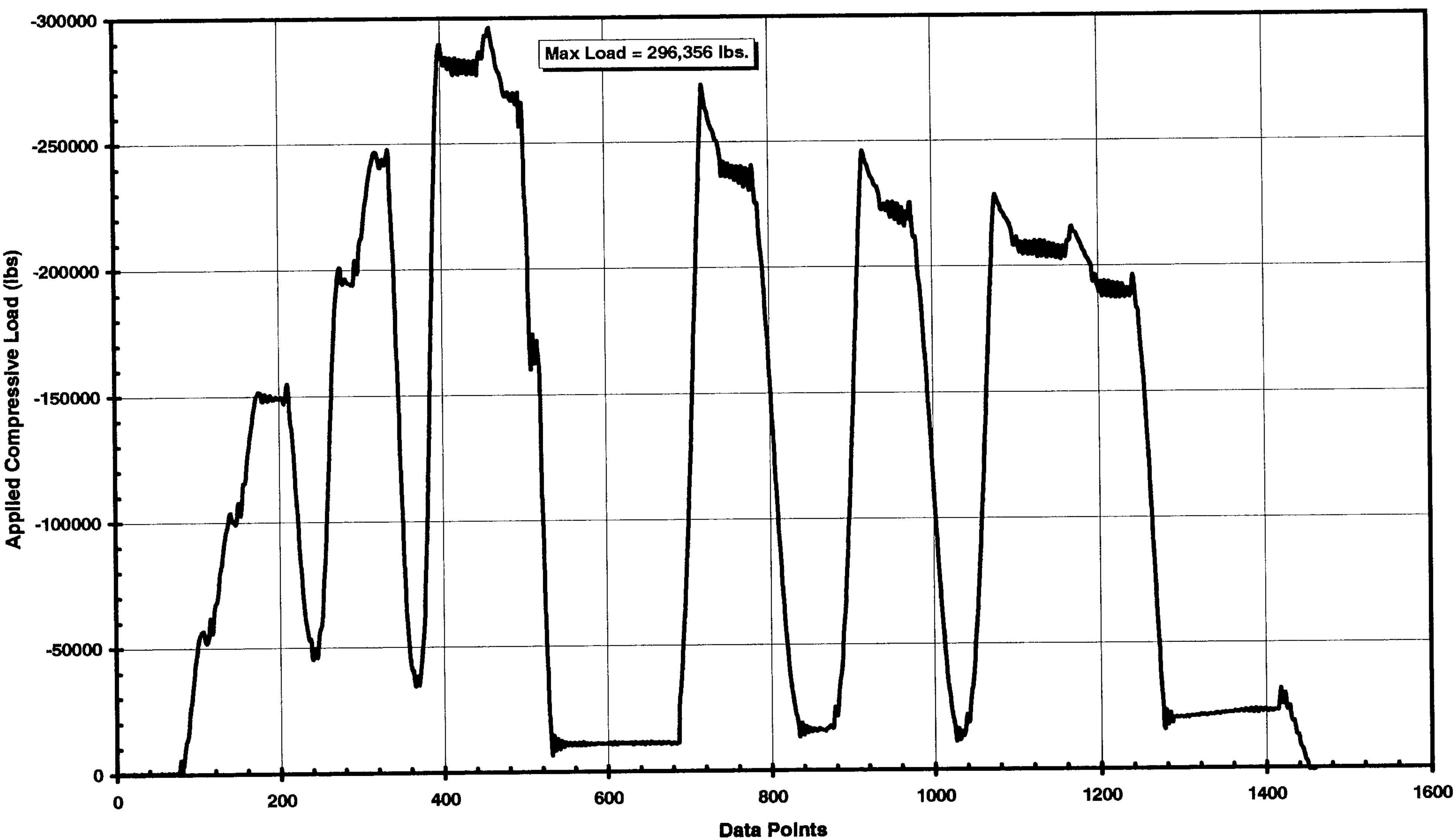

Strain vs. Applied Load
Aft Bay
Midspan
Strain Gage 53
Strain Gage 55
Strain Gage 57
Strain Gage 59
Strain (micro-in/in)
-1000
-900
-800
-700
-600
-500
-400
-300
-200
-100
0
-50000
-100000
-150000
-200000
-250000
-300000
-350000
Compressive Load (lbs)

Strain vs. Applied Load

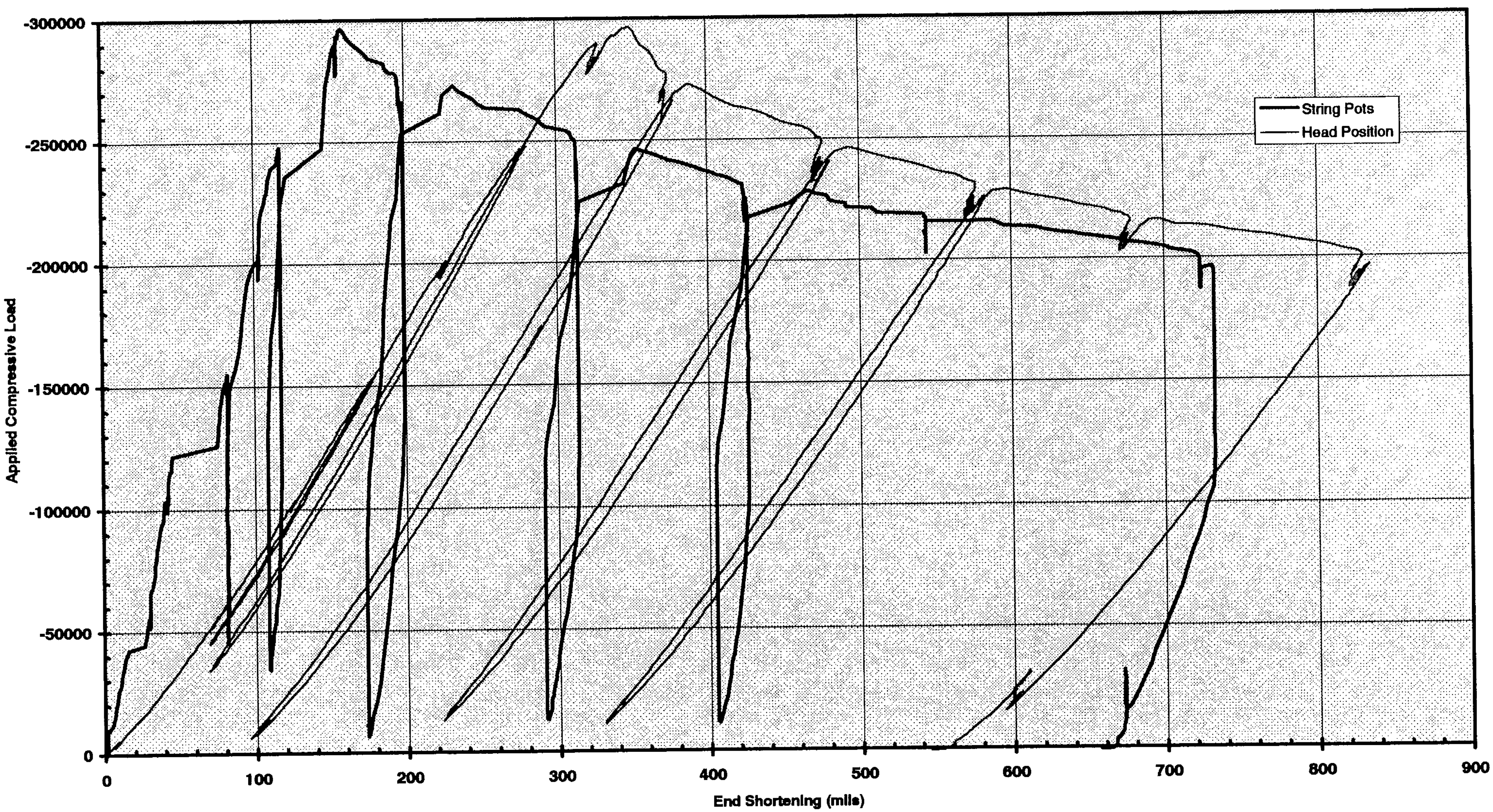


Specimen 0995 Axial and Lateral Load

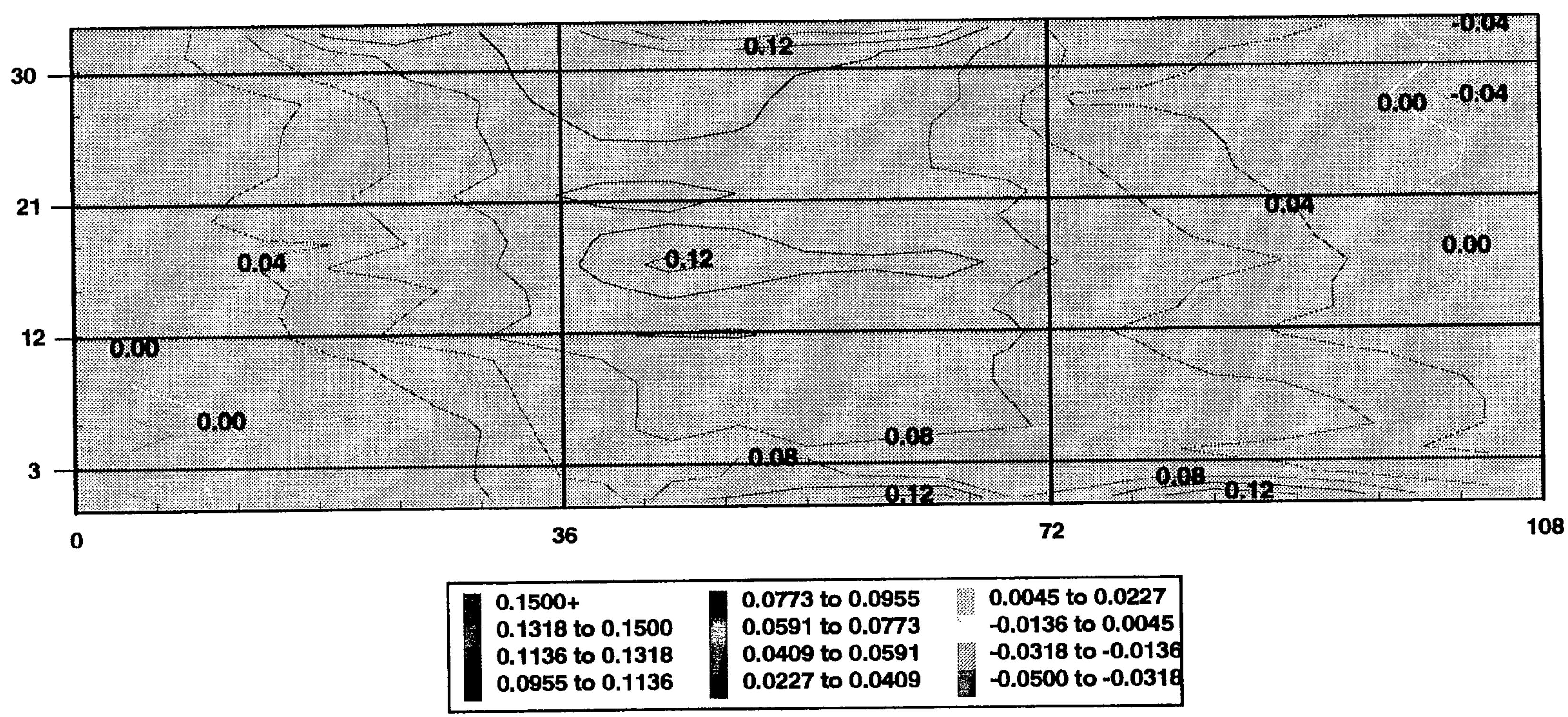
Load History



Load vs. End Shortening

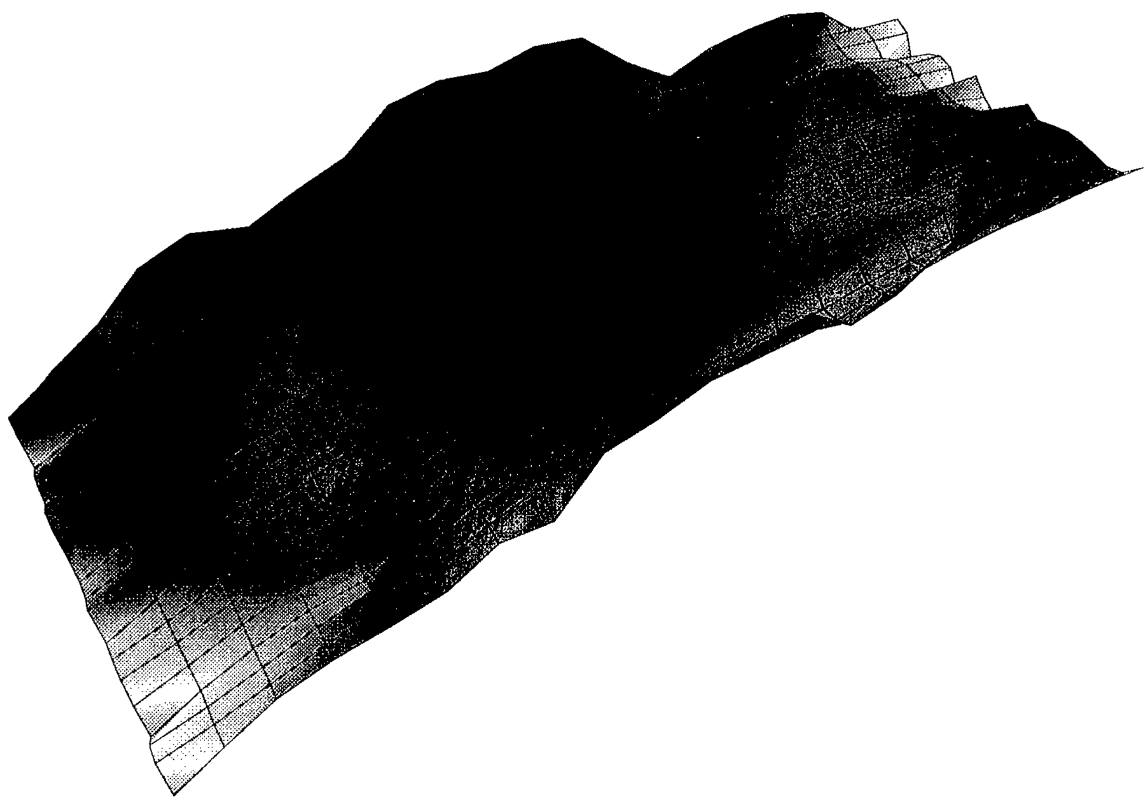


Pre-Test Survey

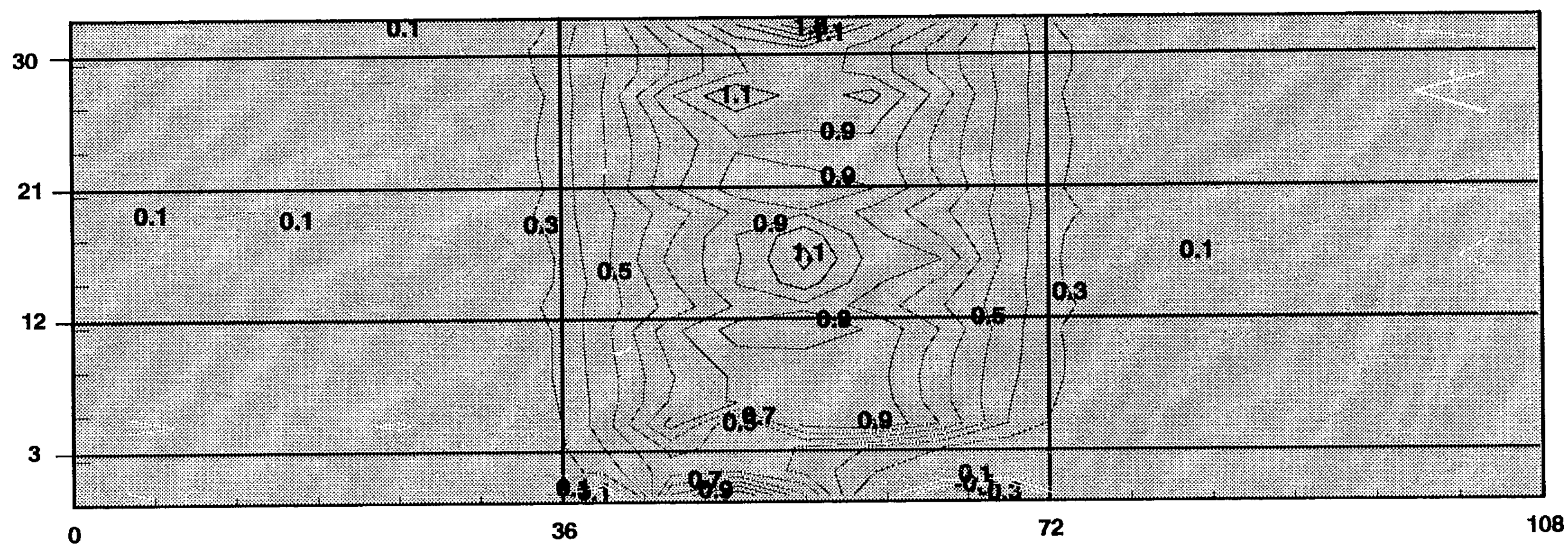


All measurements are in inches

Pre-Test Survey



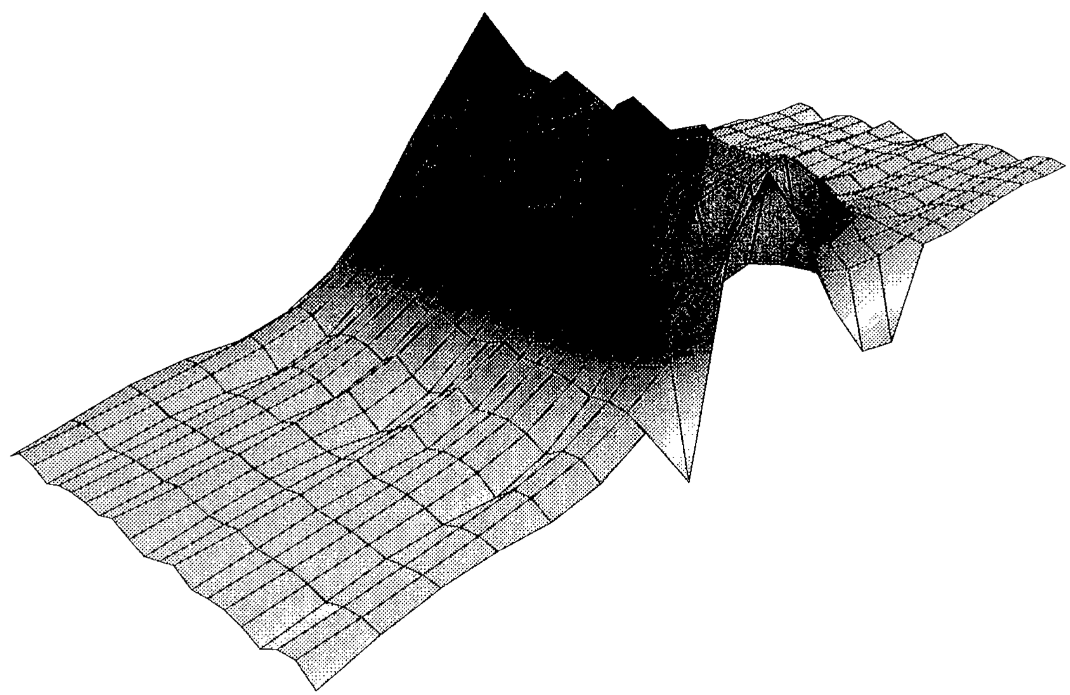
Post-Test Survey



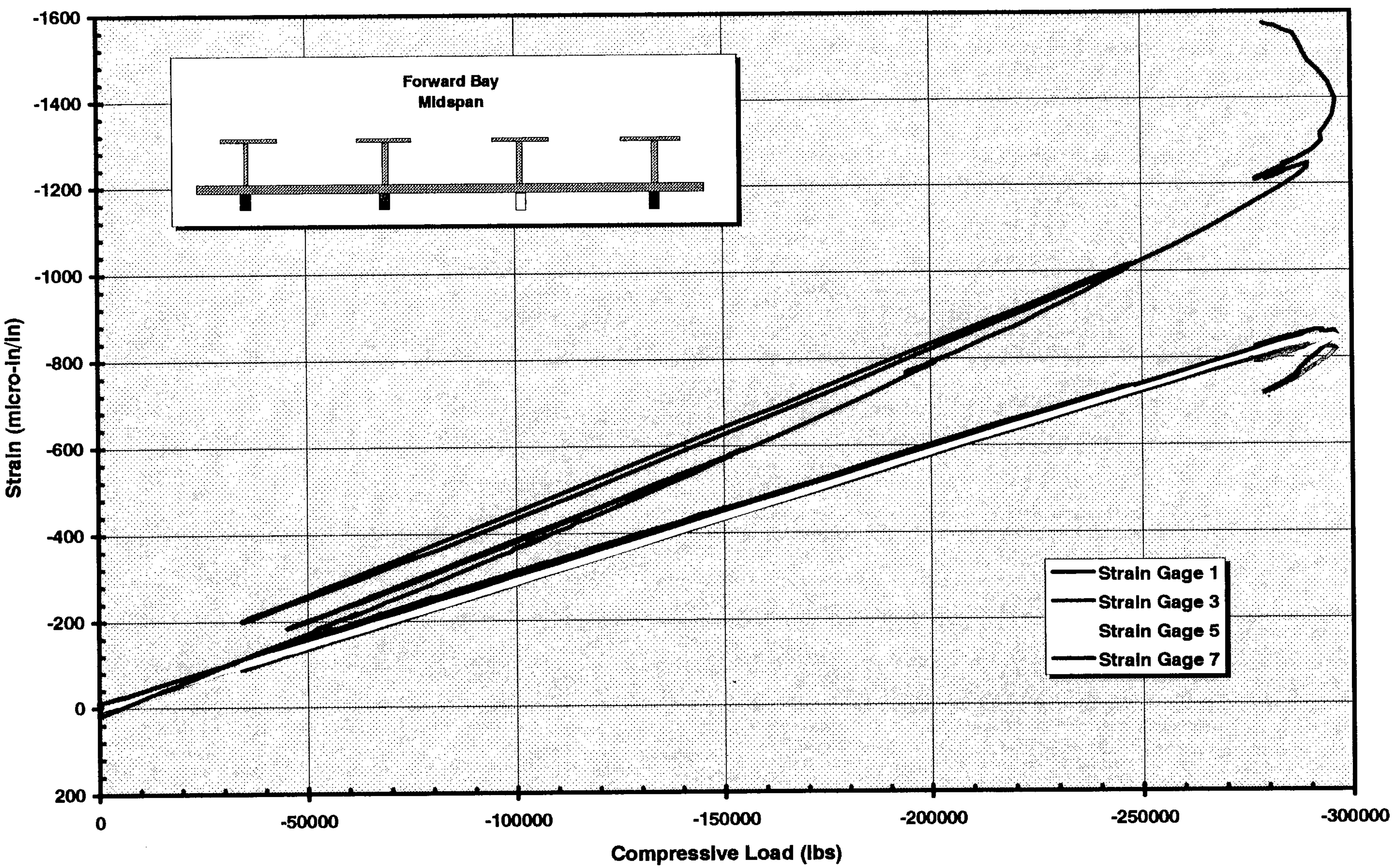
1.5000+	0.7727 to 0.9545	0.0455 to 0.2273
1.3182 to 1.5000	0.5909 to 0.7727	-0.1364 to 0.0455
1.1364 to 1.3182	0.4091 to 0.5909	-0.3182 to -0.1364
0.9545 to 1.1364	0.2273 to 0.4091	-0.5000 to -0.3182

All measurements are in inches

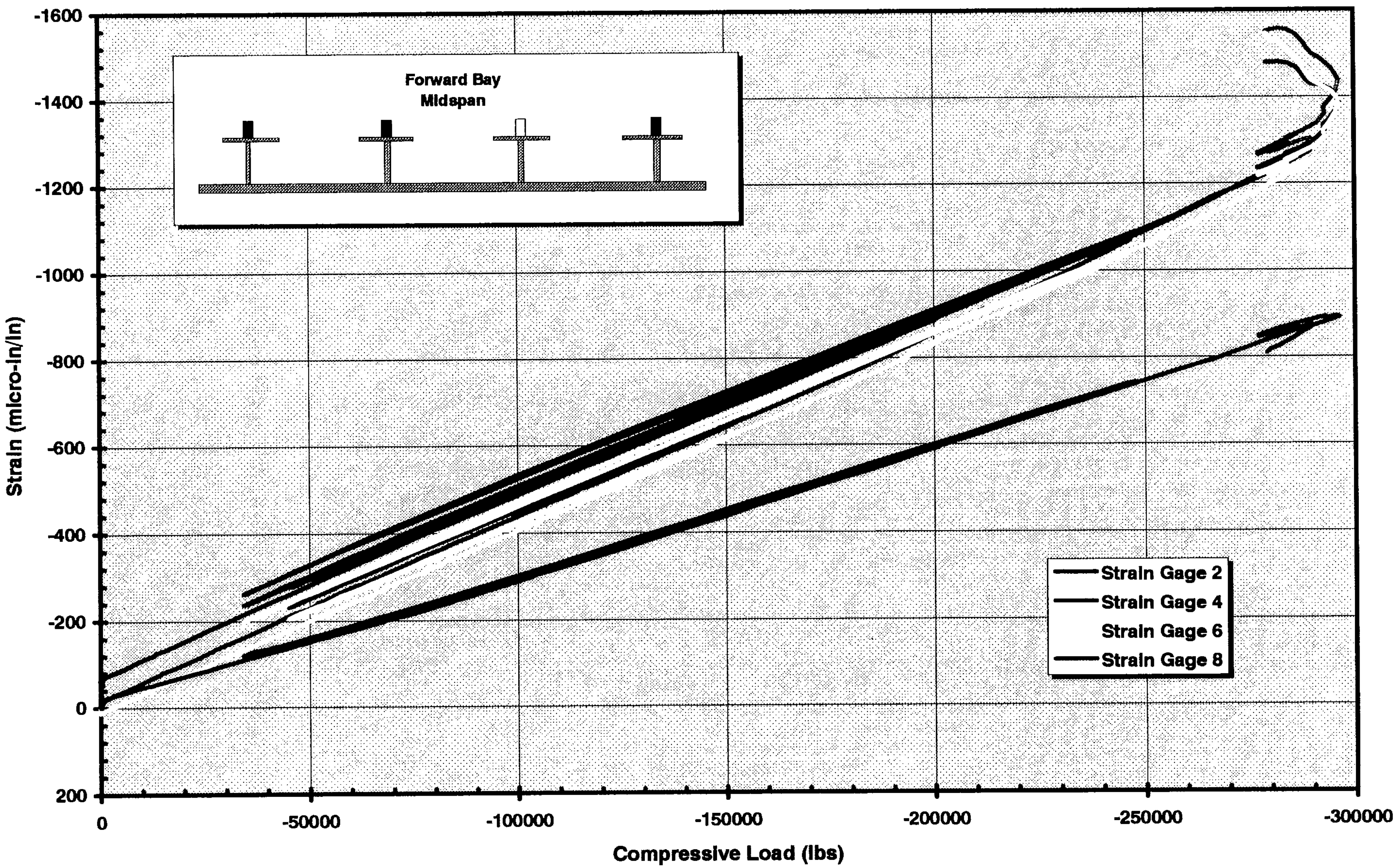
Post-Test Survey



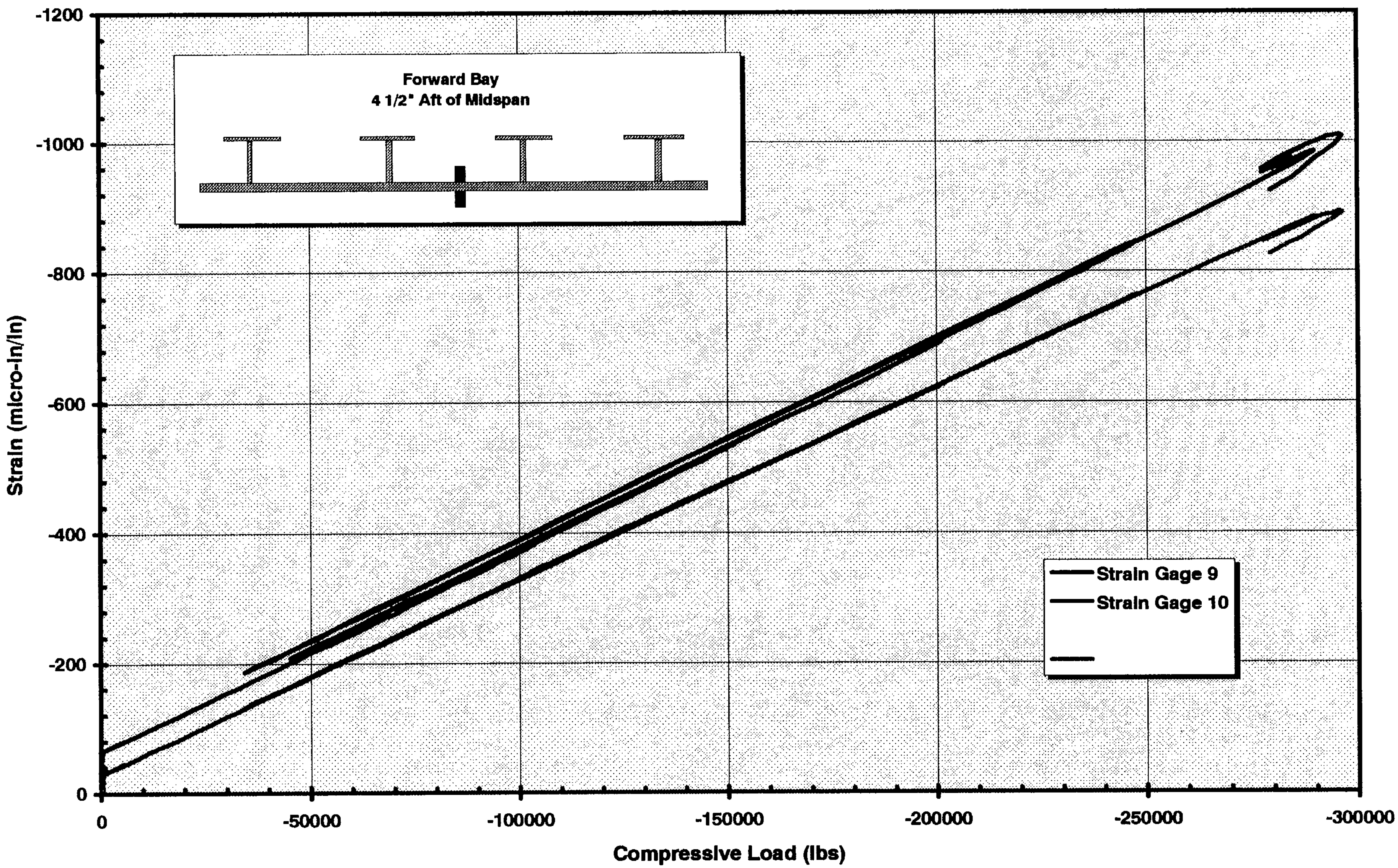
Strain vs. Applied Load



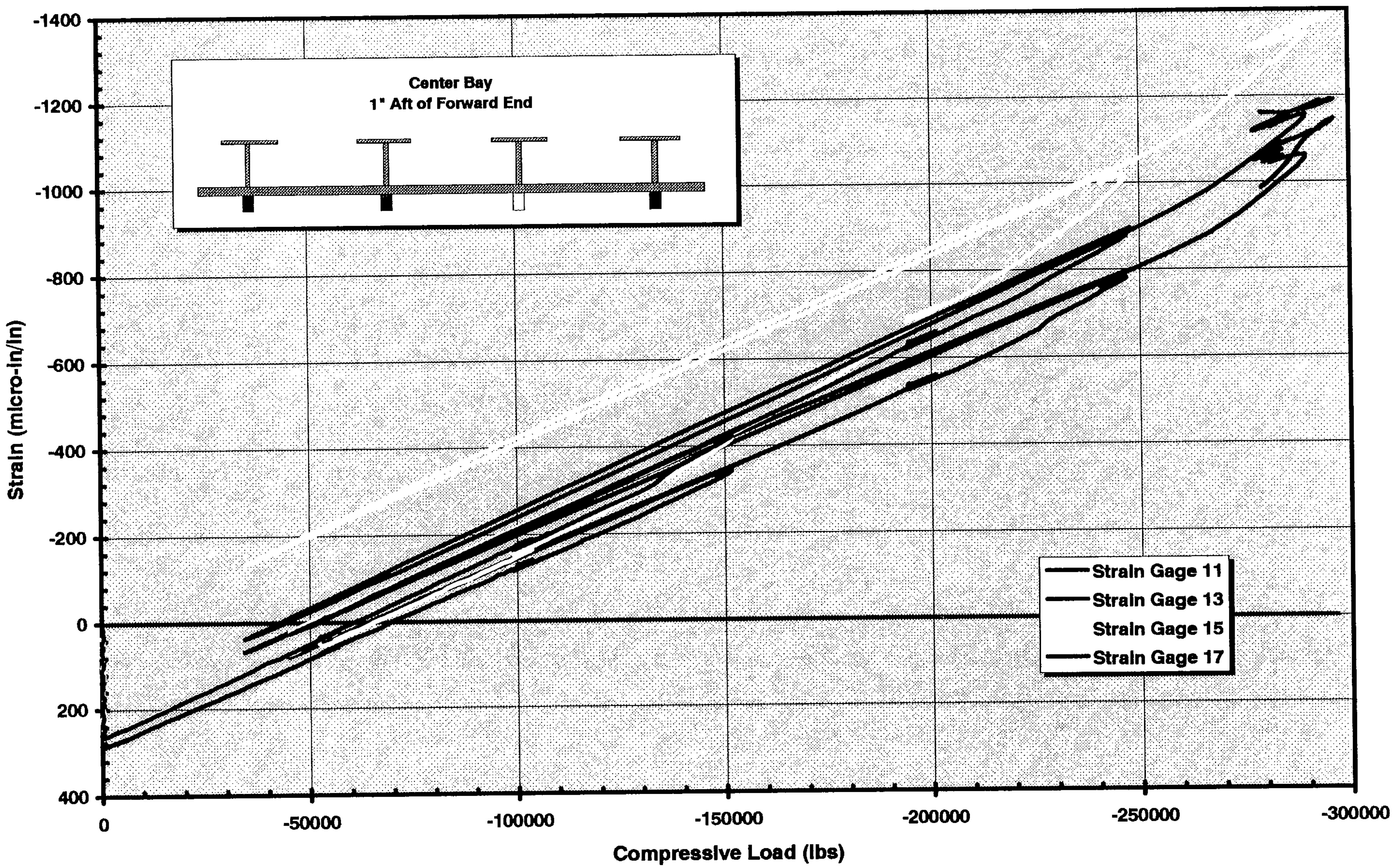
Strain vs. Applied Load



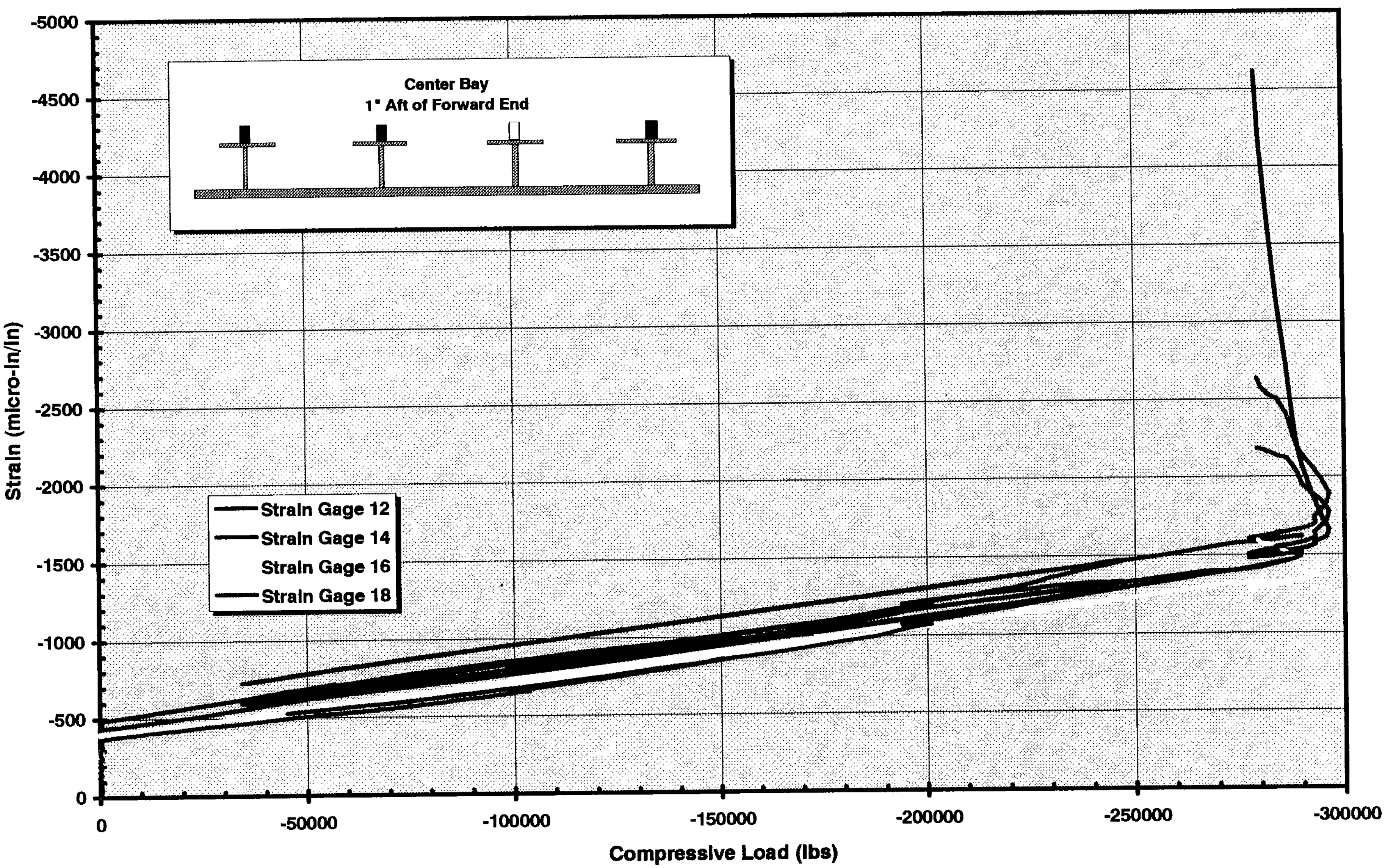
Strain vs. Applied Load



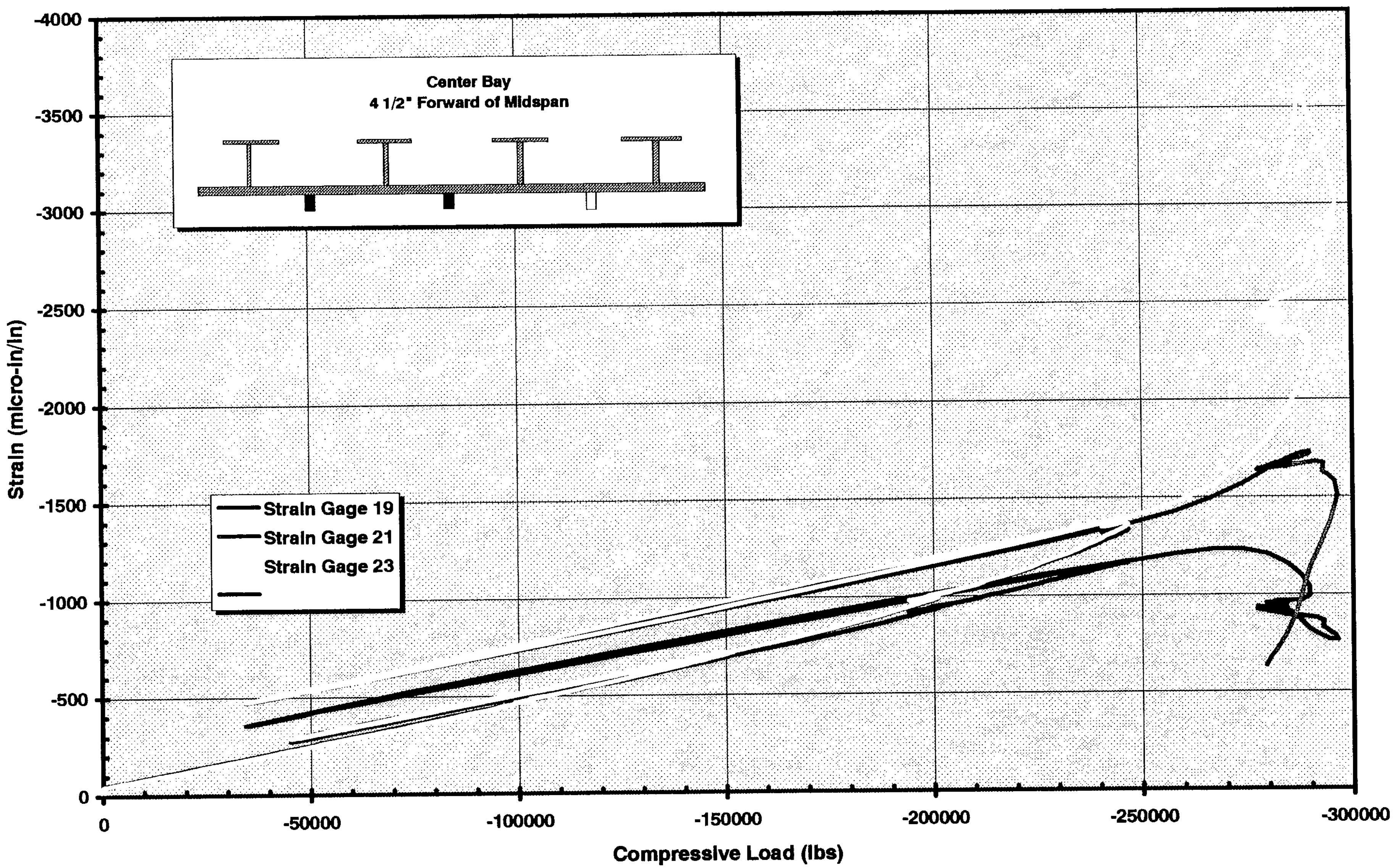
Strain vs. Applied Load



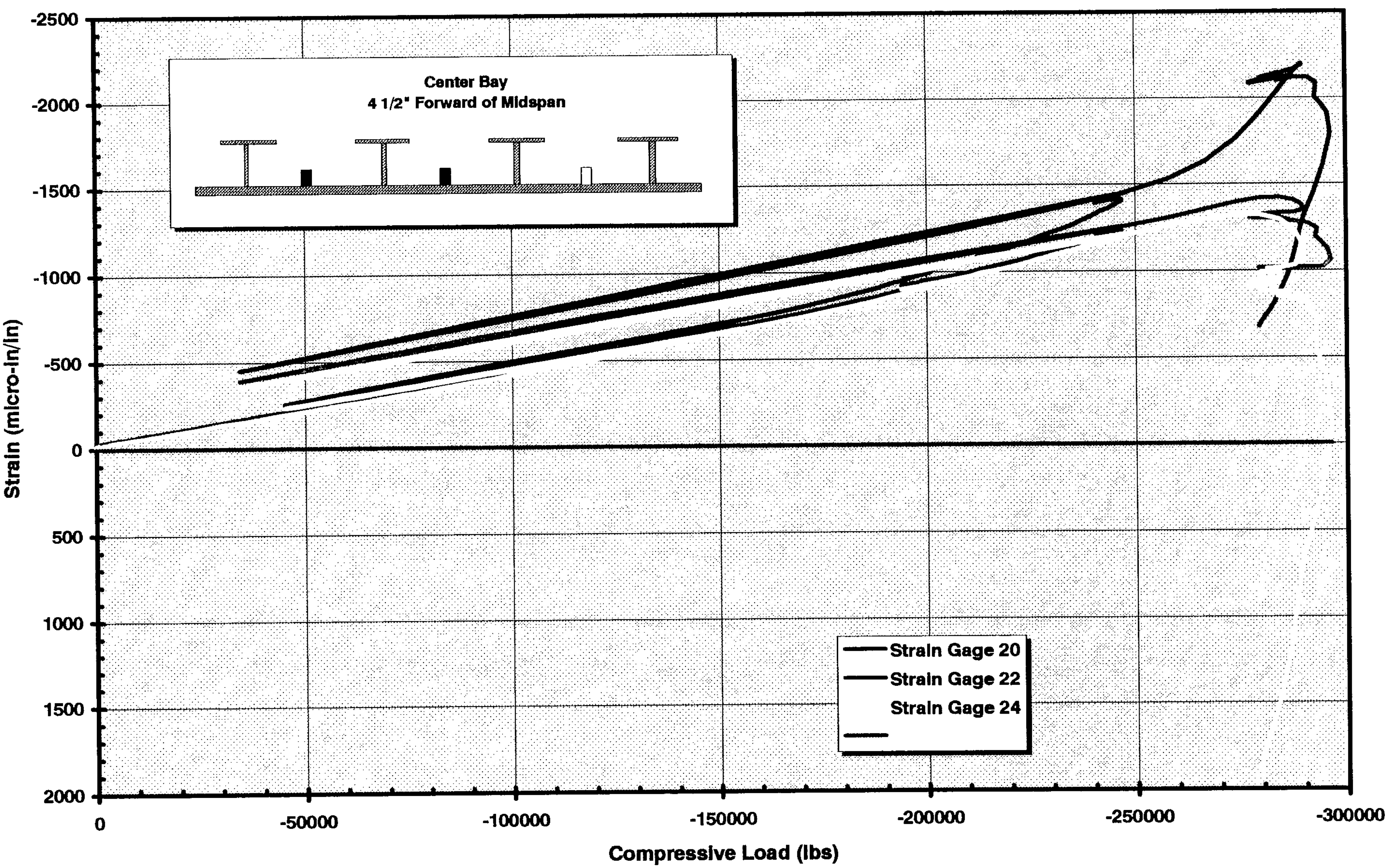
Strain vs. Applied Load



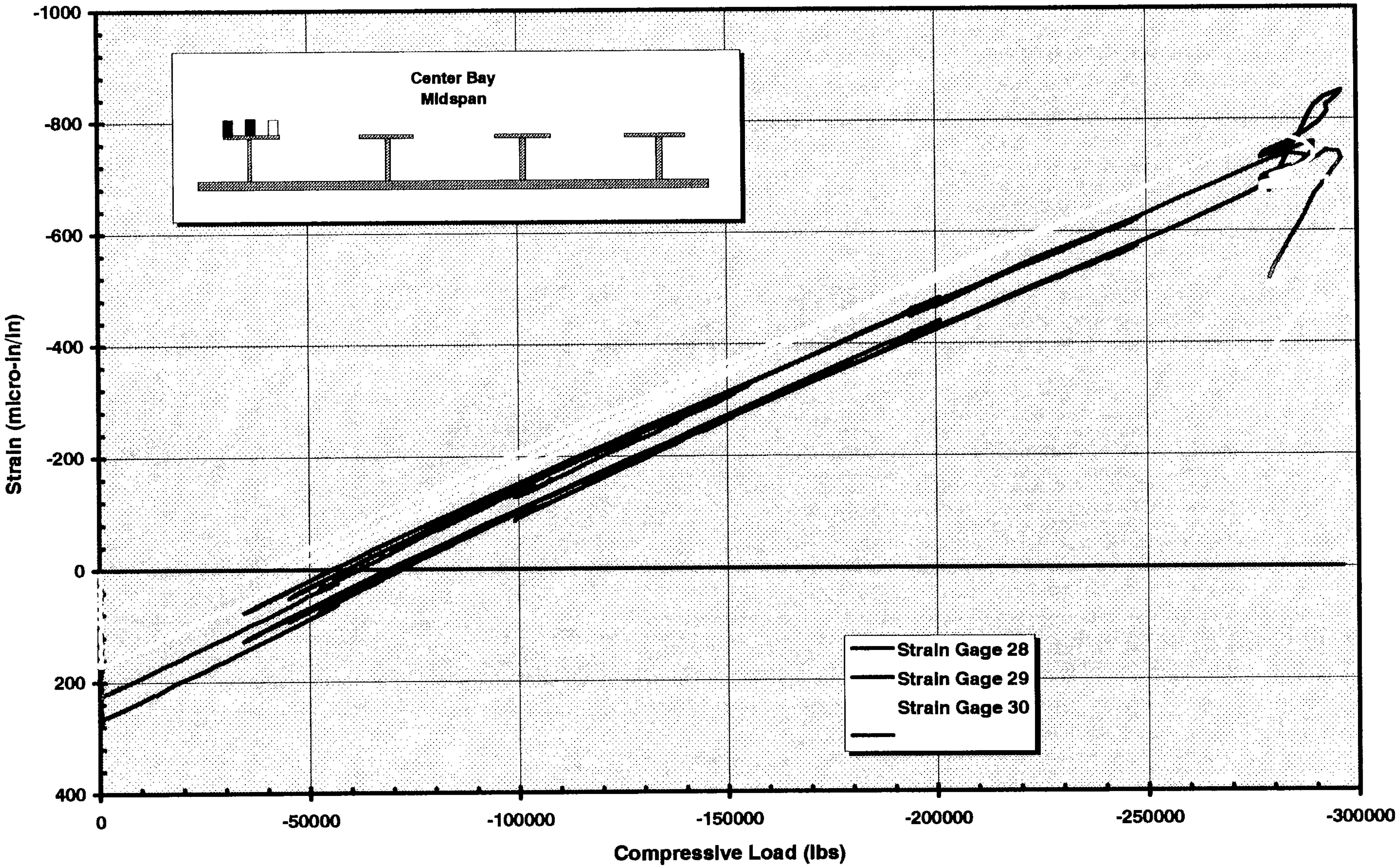
Strain vs. Applied Load



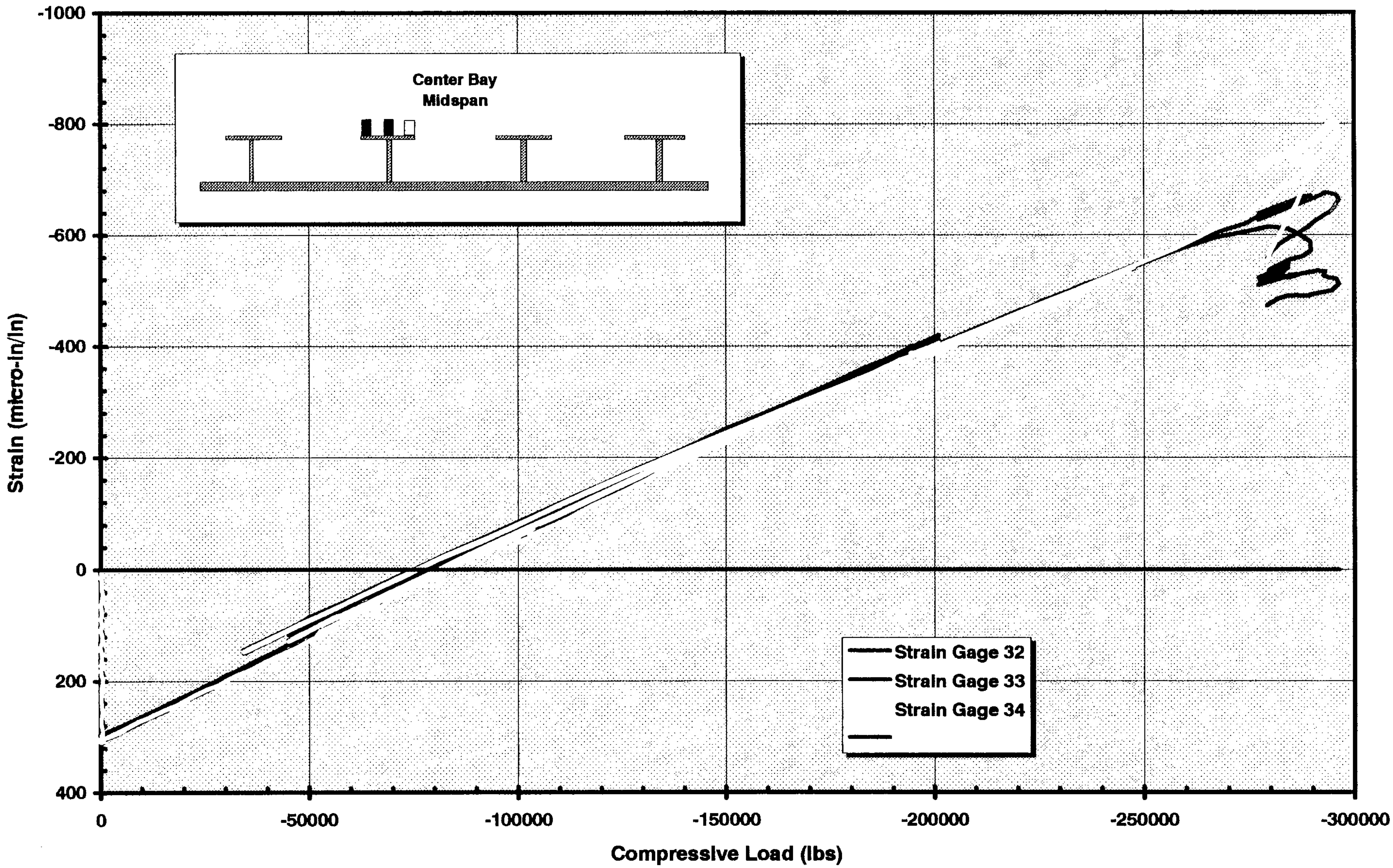
Strain vs. Applied Load



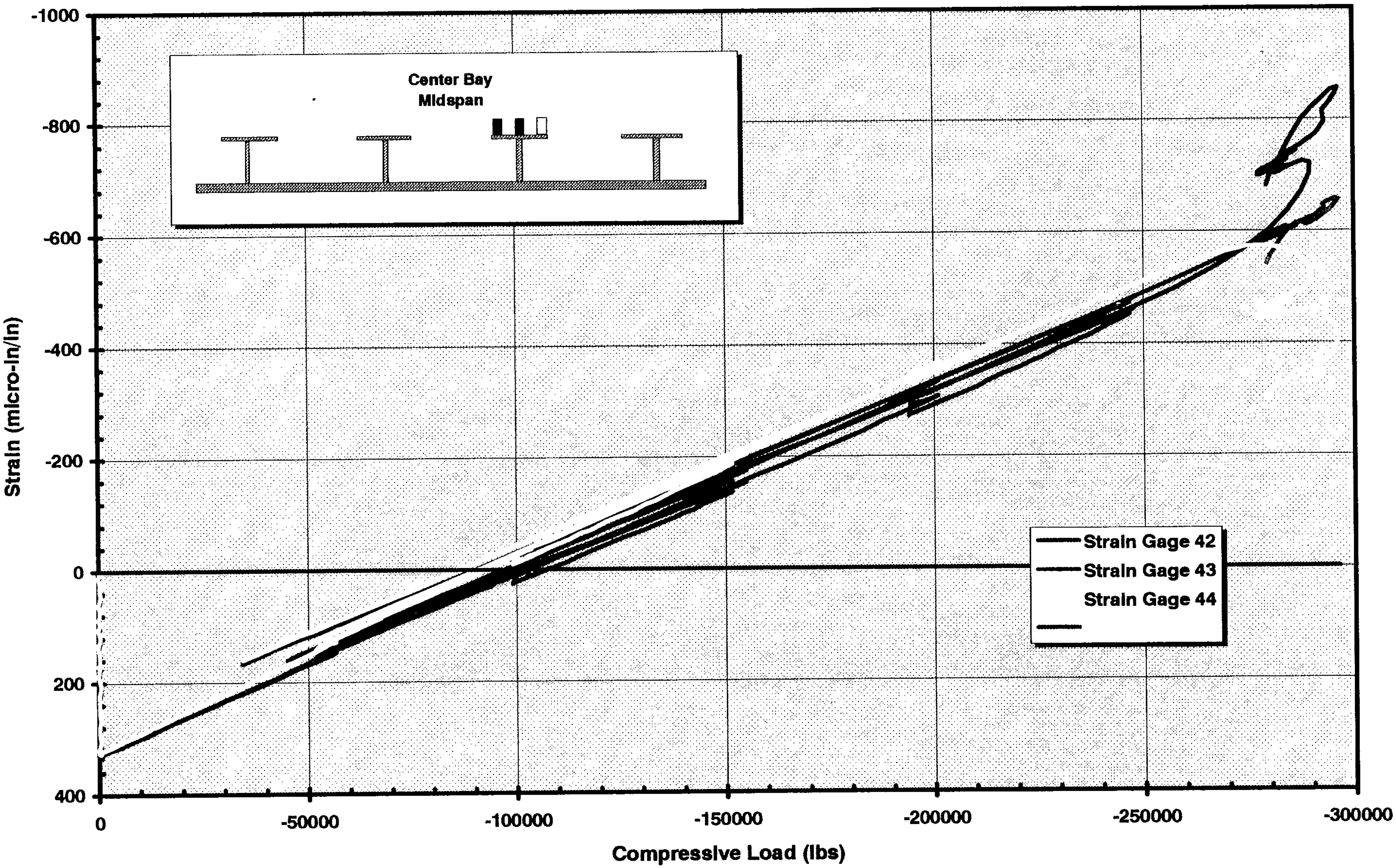
Strain vs. Applied Load



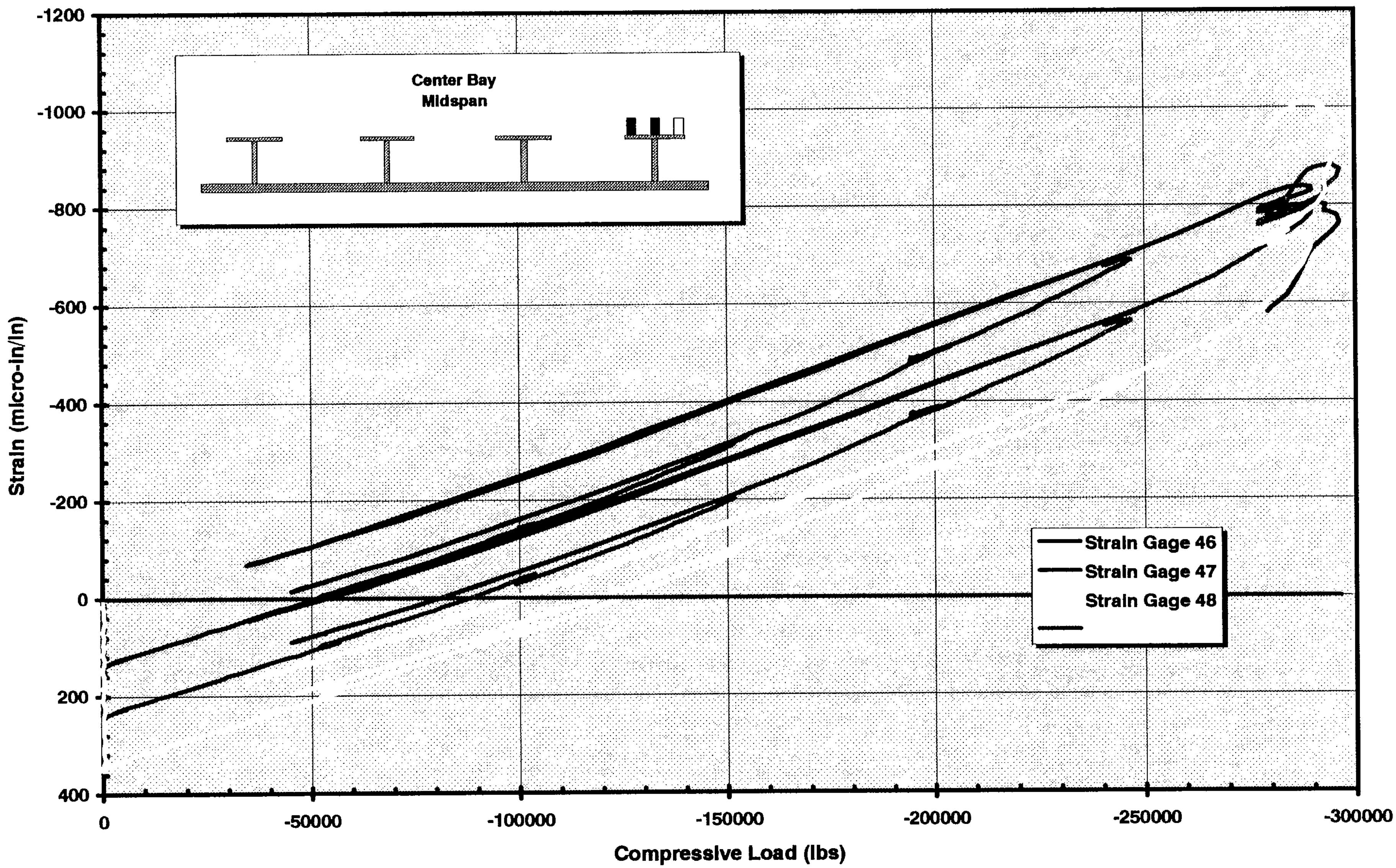
Strain vs. Applied Load

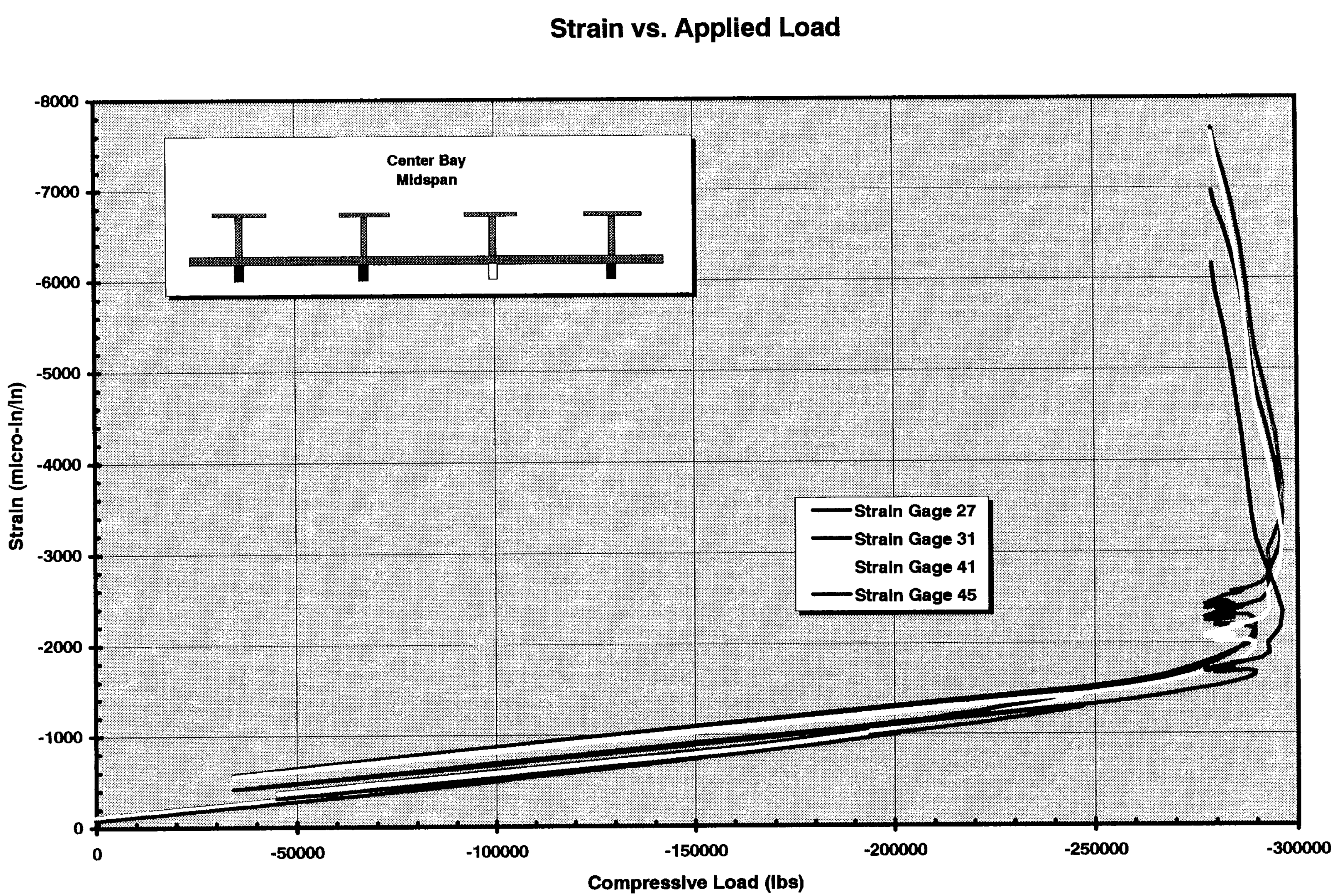


Strain vs. Applied Load

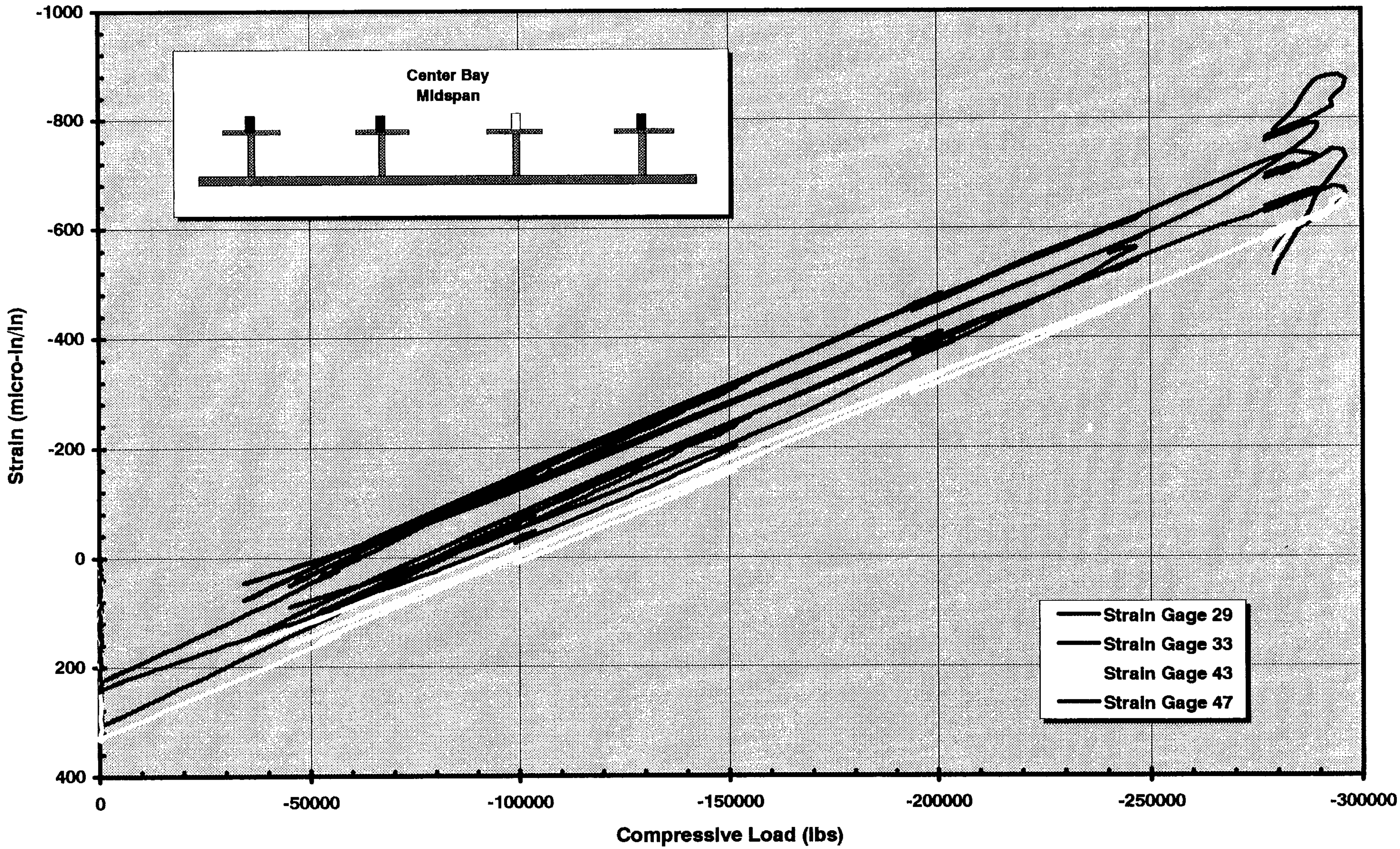


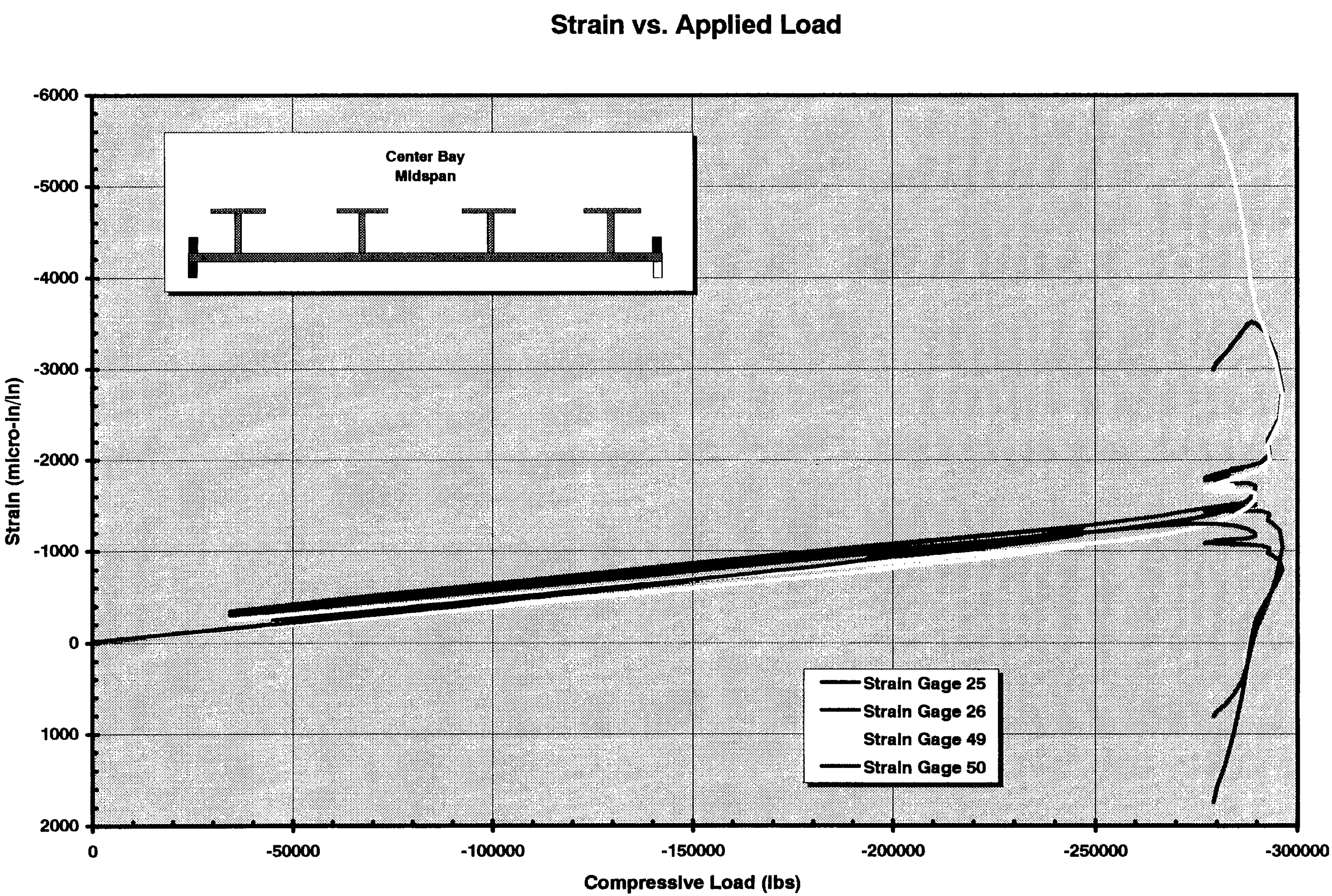
Strain vs. Applied Load



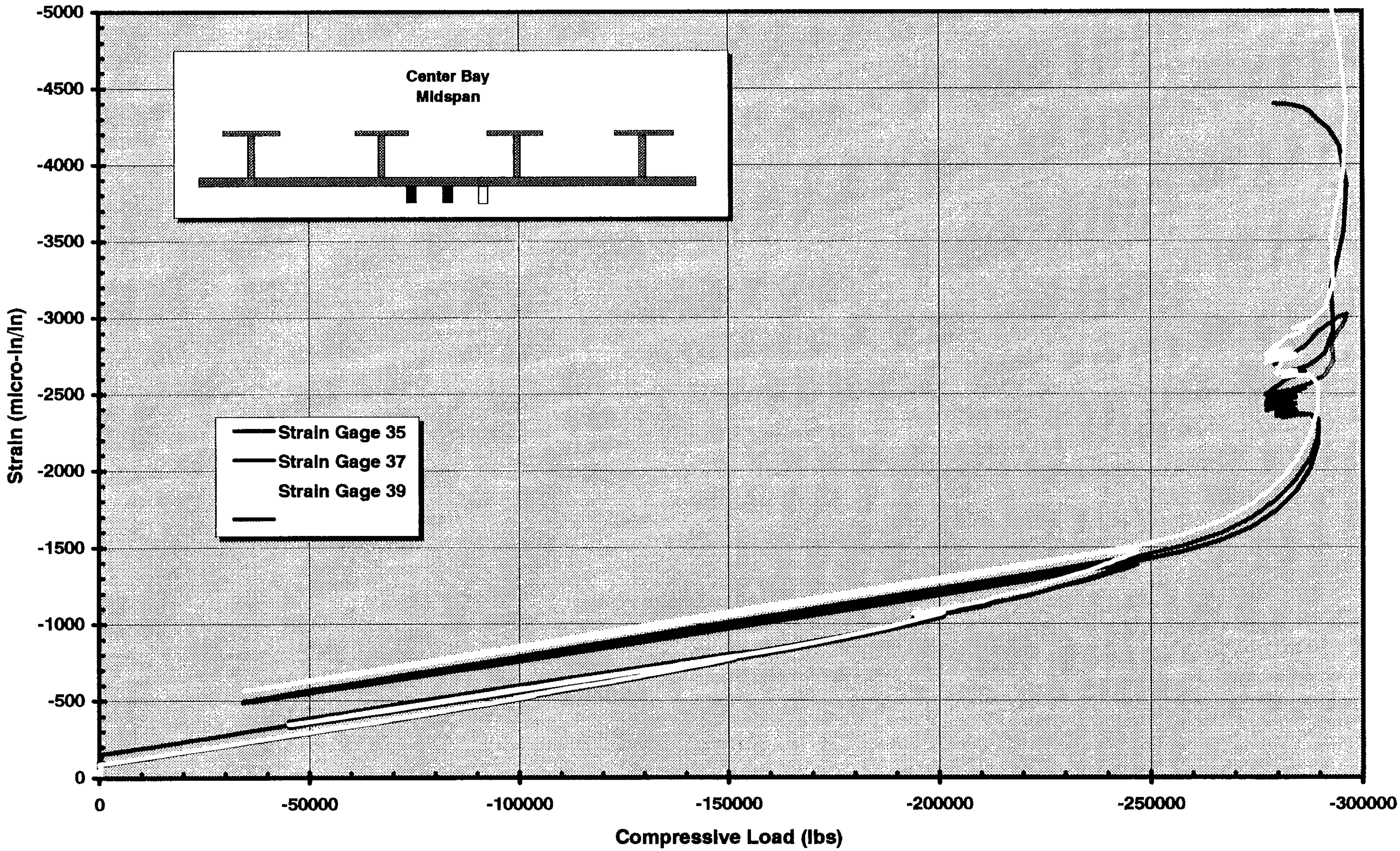

Strain vs. Applied Load
Center Bay
Midspan
Strain Gage 27
Strain Gage 31
Strain Gage 41
Strain Gage 45
Strain (micro-in/in)
-8000
-7000
-6000
-5000
-4000
-3000
-2000
-1000
0
0
-50000
-100000
-150000
-200000
-250000
-300000
Compressive Load (lbs)

Strain vs. Applied Load

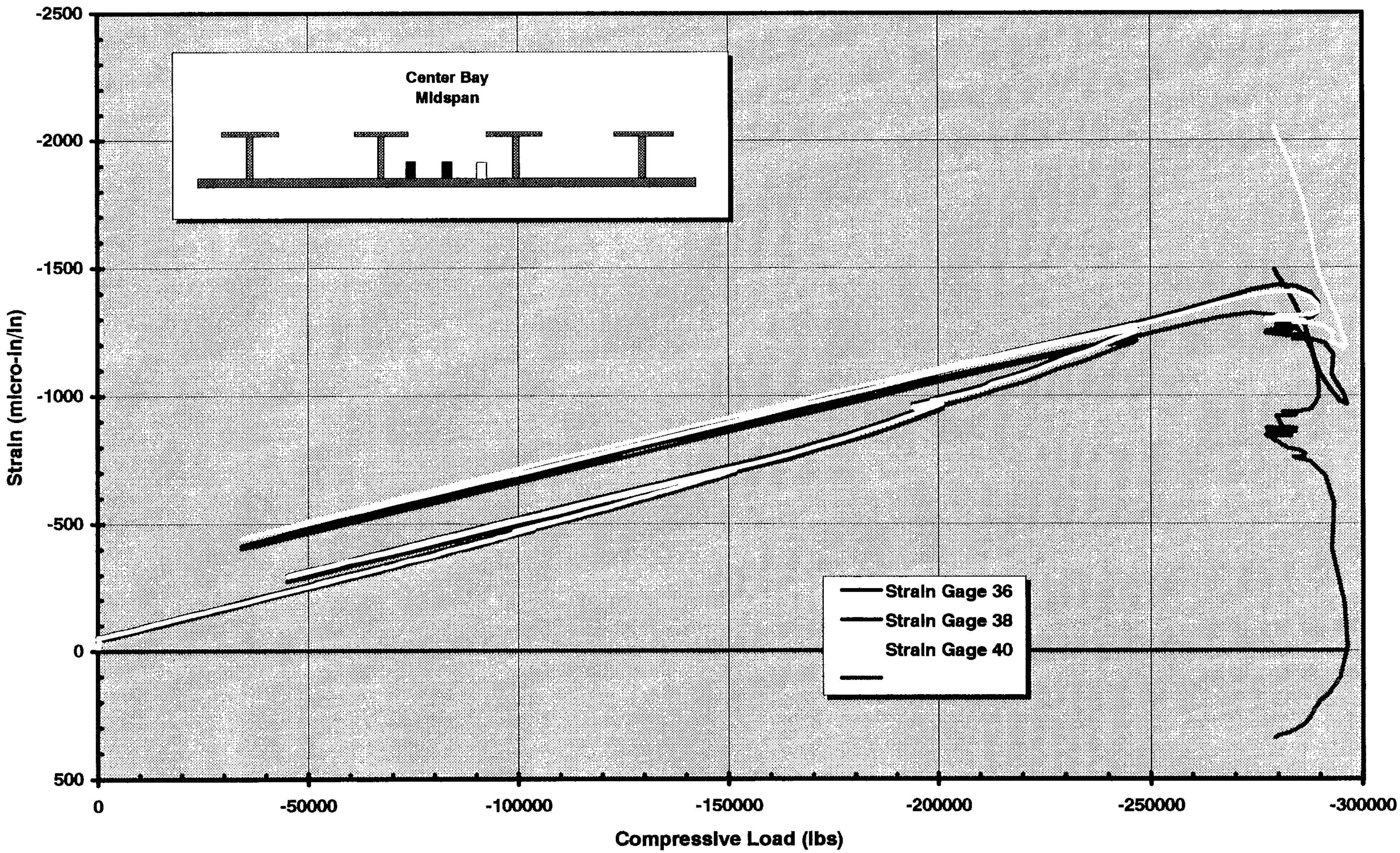


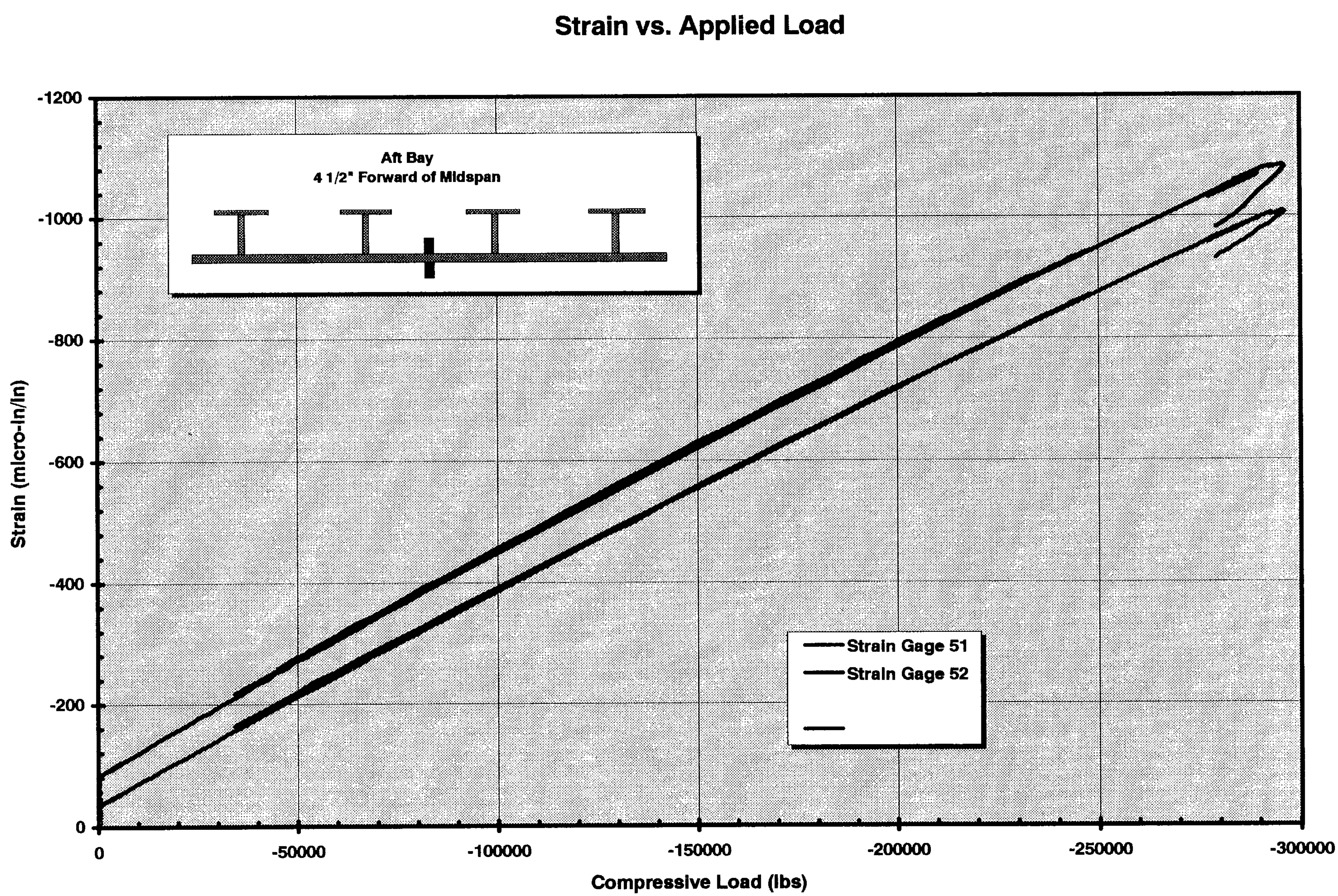

Strain vs. Applied Load
Center Bay
Midspan
Strain (micro-in/in)
-6000
-5000
-4000
-3000
-2000
-1000
0
1000
2000
0
-50000
-100000
-150000
-200000
-250000
-300000
Compressive Load (lbs)
Strain Gage 25
Strain Gage 26
Strain Gage 49
Strain Gage 50

Strain vs. Applied Load

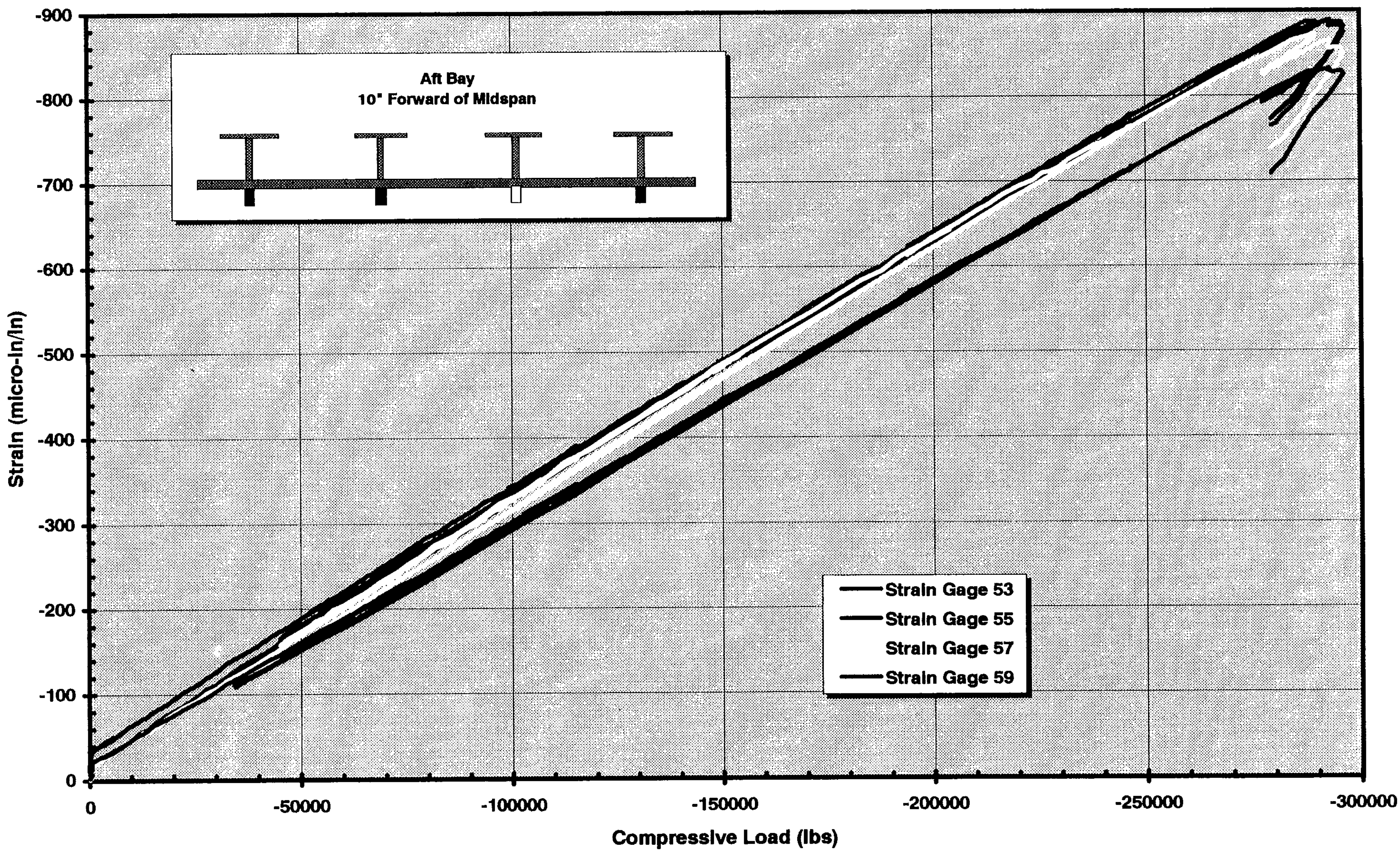


Strain vs. Applied Load




Strain vs. Applied Load
Aft Bay
4 1/2" Forward of Midspan
Strain Gage 51
Strain Gage 52
Strain (micro-in/in)
Compressive Load (lbs)
-1200
-1000
-800
-600
-400
-200
0
-50000
-100000
-150000
-200000
-250000
-300000

Strain vs. Applied Load



Strain vs. Applied Load